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Projections of Municipal Waste Management and Greenhouse Gases

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This working paper is a revised version of the working paper “Municipal waste management and greenhouse gas emissions 2008/1” that was published on 31 January 2008 under ETC’s previous name, European Topic Centre on Resource and Waste Management (http://waste.eionet.europa.eu/publications/wp2008_1/wp/wp1_2008). Some of the text is based on the previous version.

Context

The ETC/SCP has prepared this working paper for the European Environment Agency (EEA) under its 2010 work programme as a contribution to the EEA's work on environmental outlooks.

Disclaimer

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1. Executive summary

Background

In order to study the likely future trends in European waste management, the EEA and the European Topic Centre on Sustainable Consumption and Production[1] have developed a model for projecting quantities of waste and estimations of their management and the greenhouse gas emissions associated with the management. To date, this model has been applied to municipal solid waste (MSW) and construction and demolition waste (C&DW). This paper is dedicated to the MSW model only.

The goal of this project is threefold. First, the development of MSW arisings can provide information on how close Europe is towards achieving absolute or relative decoupling of waste generation from economic growth. Second, MSW management practices in the EU are translated into GHG emissions, demonstrating on one hand the potential effect of waste-related activities on global warming, as well as mitigation possibilities through improvements in MSW management that might help countries meet their targets regarding reductions in GHG emissions. Third, the analysis of GHG emissions according to treatment options serves the purpose of investigating the incentive of European legislation towards improving European waste management. The time interval covered by the model was set to the period 1990-2020. The beginning of this period was characterised by the first observed rapid changes in European MSW management and the end of the period is a threshold year for many European waste legislative targets.
The results of the model have already been presented in an EEA short report in 2008 (EEA, 1/2008). In that paper, the conclusions were that absolute decoupling is not likely on a European level, but rather that only some individual countries are approximating decoupling. The potential for global warming mitigation due to better MSW management was also described. However, this paper presents more comprehensive results based on further efforts to increase their credibility and robustness.

The quantity of municipal waste is projected with reference to an econometric scenario published by the European Commission which takes into account the full effect of the global economic downturn that started in 2008. The generation of municipal waste is projected to be approximately 255 million tonnes in the EU-27[2] + Norway and Switzerland in 2010 with a further increase to around 279 million tonnes in 2020. Waste generation per inhabitant has been on the increase for years and, according to the projection, this will continue till 2020, with a small setback around the period 2008-2010 due to the impacts of the economic downturn. In 2005 the EU-27 + Norway and Switzerland generated 524 kg municipal waste per person, and it is estimated that by 2020 this will escalate to around 558 kg per person.

Management of municipal solid waste

Landfill of municipal solid waste has been the predominant option in the EU-27 + Norway and Switzerland on aggregated level for several years but this is changing. In 1995 the average landfill rate was 68% but in 2007 this had fallen to 40%. The diversion of MSW away from landfill is expected to continue, so that only 28% of MSW would be landfilled in 2020. Recycling of municipal waste is assumed to reach a level of 49% and incineration of waste with energy recovery 23% in 2020. This future distribution of landfill, incineration with energy recovery and recycling represents a business-as-usual scenario that is based on an assessment taking into account previous developments in municipal waste management and the implementation of planned policy measures. Still, the

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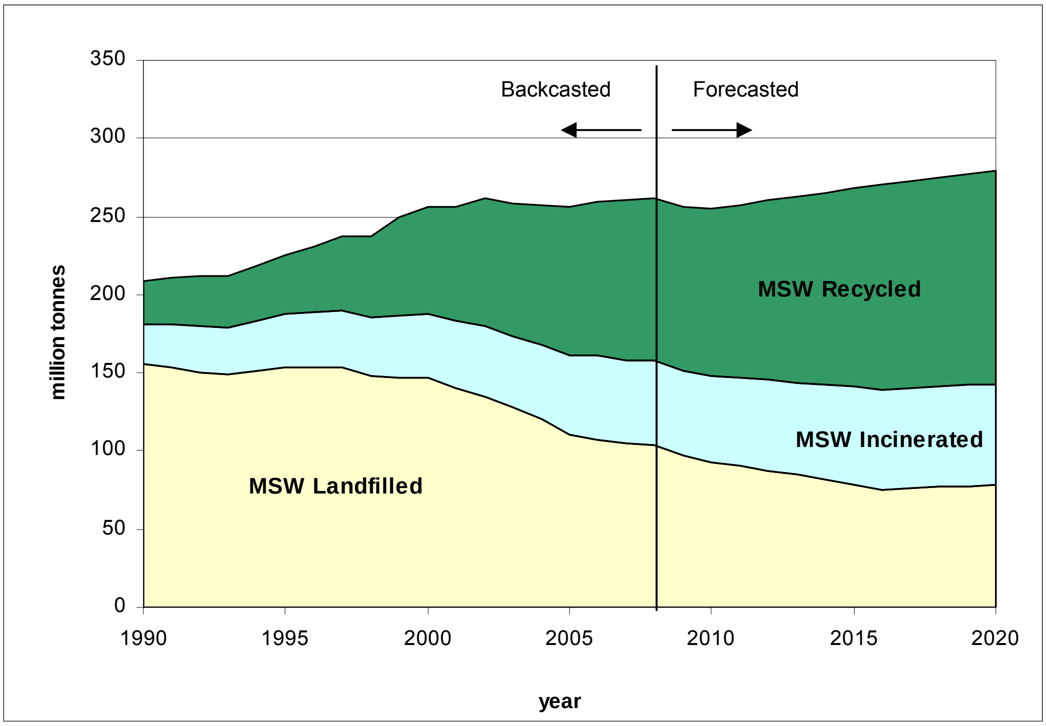
[1] also under the previous name until 2008, European Topic Centre on Resource and Waste Management

[2] EU-27 refers to all EU member states except for Cyprus. For the remaining EEA members, no sufficient data were available.

projection shows that due to the considerable increase in waste amounts, a slight increase in the absolute amount of landfilled waste is seen from 2017.

The development in waste generation and treatment for the period 1990 to 2020 for this scenario is presented in the figures below.

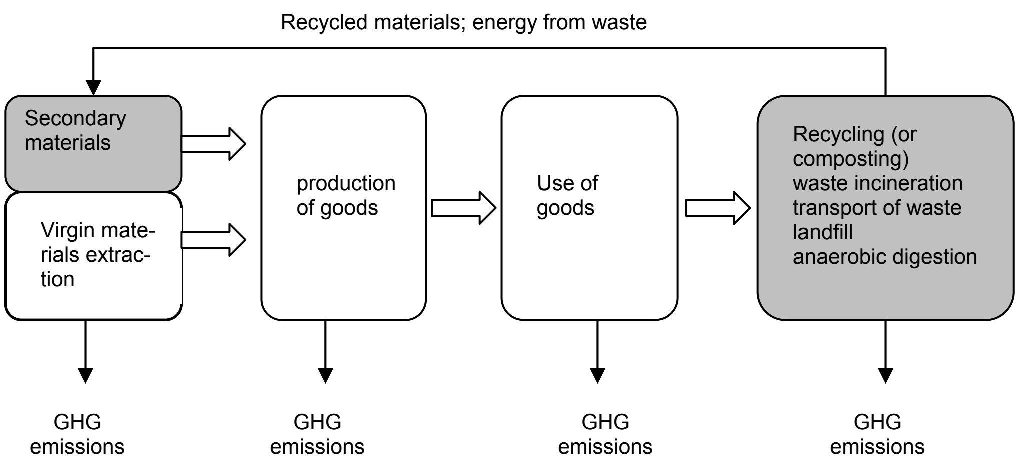
Figure 1.1 Projected generation and management of municipal waste in the EU-27 + Norway and Switzerland



GHG emissions from municipal solid waste management

In this report, effects of municipal solid waste management on GHG emissions are investigated. Figure 1.2 shows which processes from a product's traditional life cycle are included in the model (in dark font).

Figure 1.2 Life-cycle and coverage of the model in this report



In order to see the overall effect of waste management, the avoided emissions (counted as negative) are added to the direct emissions, giving the net greenhouse gas emissions from MSW management. Direct emissions are caused by all activities directly involved in the waste management system itself (table 1.1). They include mainly methane emissions from landfills, energy-related GHG emissions from collection, and transport of waste and emissions from waste incineration and recycling plants. Avoided emissions are the GHG emissions from activities such as energy production from fossil fuels and production of primary materials that would be generated if there was no (0%) energy recovery from waste incineration and from landfill methane recovery, and no (0%) material recuperation from waste recycling. In this report, only anthropogenic emissions are presented in the results, although the biogenic emissions are also separately calculated.

Table 1.1: Overview of processes and emissions covered by the model

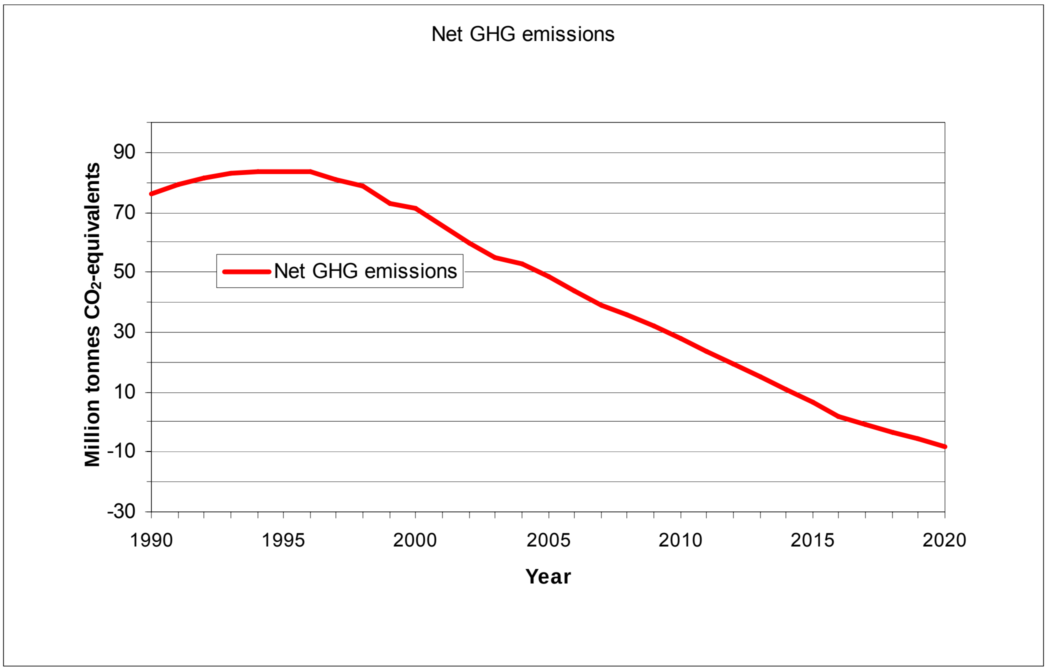
Direct emissions	**Avoided emissions**
GHG emissions from landfill	Emissions avoided due to energy generation from landfill gas
GHG emissions from waste incineration	Emissions avoided due to energy generation from waste incineration
GHG emissions from recycling processes	GHG emissions avoided due to use of recycled materials instead of virgin materials
GHG emissions from composting	GHG emissions avoided due to use of compost instead of virgin materials
GHG emissions from anaerobic digestion	GHG emissions avoided due to use of energy generation from landfill gas and to use of compost instead of virgin materials
GHG emissions during transport of waste	

The net greenhouse gas emissions from the management of municipal waste are estimated to decline by around **85 million tonnes of CO_2-equivalents** between 1990 and 2020 in EU-27 + Norway and Switzerland. From the year 2017, the avoided emissions from waste management activities are higher than the burden caused by direct emissions from landfill sites, incineration plants, recycling activities and the collection and transport of MSW.

The revised 1996 IPCC Guidelines describe in detail how to estimate greenhouse gas emissions from waste management and are used by countries to prepare their annual greenhouse gas inventory under the UNFCCC. In this report, the estimation of direct greenhouse gas emissions from landfill and incineration are based on recommendations of the IPCC Guidelines. Life-cycle information has been used to estimate emissions from recycling and the avoided emissions.

Figure 1.3 presents the development of the net greenhouse gas emissions from the management of municipal waste in EU-27 + Norway and Switzerland.

Figure 1.3 Projected GHG emissions associated to MSW management in EU-27 + Norway and Switzerland (baseline scenario)



A key finding is that mainly increasing recycling and second, increasing incineration rates of municipal waste can reduce the emissions of greenhouse gases and, if high rates of recycling and possibly incineration with energy recovery are attained, more emissions are avoided than generated via waste management (i.e. net emissions are 'negative') around 2017. Between 2017 and 2020, the recycling share is expected to stabilise at 49%. The further decrease of the net GHG emissions is in the model caused by the projected increase in MSW generation and thus higher avoided emissions.

If avoided emissions are higher than direct emissions, one could conclude that it would be better for the environment to generate and recycle more waste. That is of course not the case. The reason is that the model only focuses on waste management and not the full production chain and its consequences in a life cycle perspective (figure 1.2). Therefore, the increasing consumption of goods (and resulting generation of more municipal solid waste) is more harmful for the environment, if all life-cycle stages of materials were taken into account. Including these life-cycle stages in the model would however be very complicated and require many more resources. However, the dependence of GHG emissions calculations on economic developments is evident since future increased private consumption leads to lower GHG emissions from waste management. The economic crisis affects greatly the consumption patterns across Europe, leading to reduced amounts of waste. The generation of waste, though, is critical for calculating GHG emissions.

Therefore, improving municipal waste management, by promoting alternatives to landfilling, leads to a relative reduction of net GHG emissions over time. This decrease contributes to meeting greenhouse gas reduction targets, such as the 2008–2012 Kyoto Protocol targets or the 2020 targets under the climate change and energy package of the EU.

As mentioned above, net emissions are the result of adding the direct and avoided emissions. Figure 1.4 below gives an example of how each of the treatment paths and collection of MSW contributes to the net results.

Figure 1.4 Net greenhouse gas emissions from municipal waste in EU-27 + Norway and Switzerland, baseline scenario (million tonnes CO_2-equivalents)

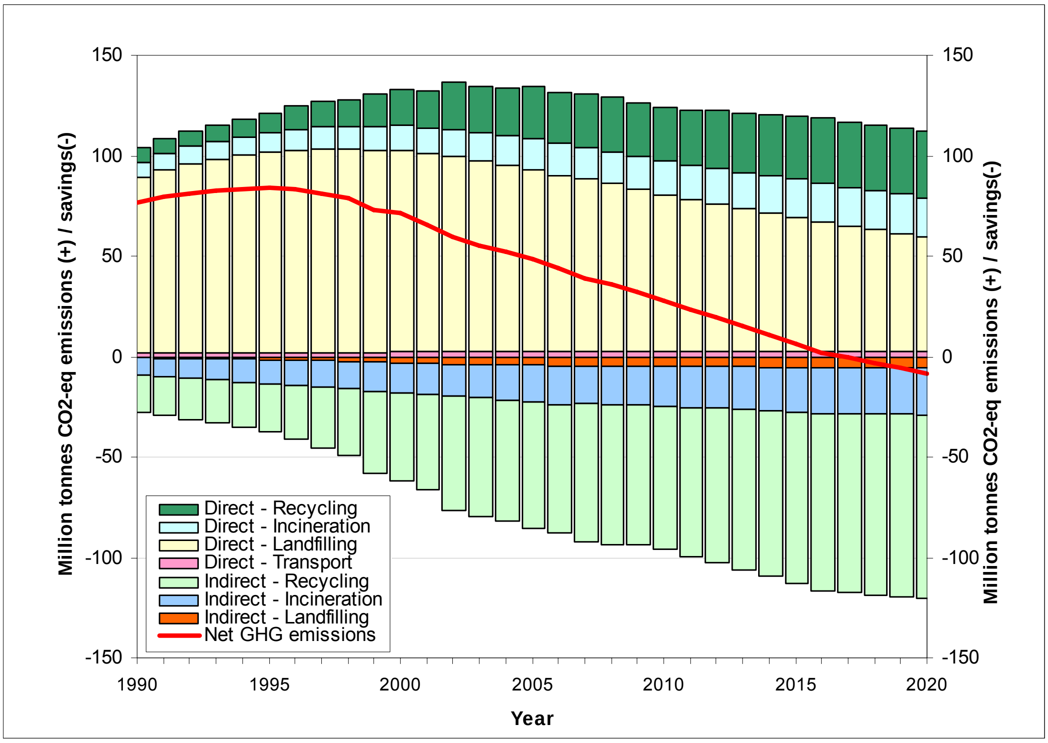


Figure 1.4 allows for a more detailed analysis in pursuing the reasons behind the reductions in net GHG emissions. It shows that direct emissions are clearly decreasing after 2005 in spite of growing MSW generation, triggered by better MSW management. At the same time, more and more emissions are avoided. The benefit from the energy recovery in landfills is much smaller than the corresponding benefit from material recovery. The avoided emissions from recycling constitute more than 75% of the total avoided emissions. It is safe to say that recycling is mainly responsible for the rapid decrease in MSW net GHG emissions after the year 2000.

Three projection scenarios

In addition to the baseline scenario described above, two other policy scenarios have been applied:

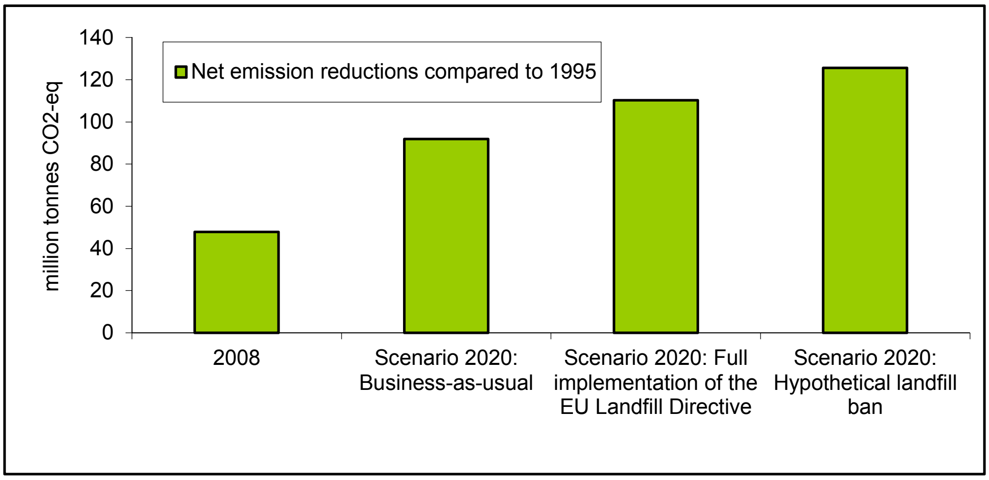
- Landfill Directive scenario (LS): This scenario assumes that all countries will fully fulfil the Landfill Directive's targets to divert biodegradable municipal waste from landfill, taking into account the derogation periods for countries with high landfill rates.
- Landfill Ban scenario (LB): This scenario assumes a hypothetical ban on landfilling of all MSW in all EU 27 countries plus Norway and Switzerland by 2020.

These scenarios have the purpose to illustrate the implications for GHG emissions, if countries decided to intensify their efforts towards better waste management. Since according to the baseline scenario, diversion of waste from landfill is crucial for reducing GHG emissions from waste management, the two alternative scenarios simulate decisions that target landfilling. The generation of waste is kept the same in all three scenarios.

In the graph 1.5 below, all the results from the different simulated scenarios are presented for three threshold years: 1995 is the first year where data on waste generation and management is available, 2008 is the latest date where historical data are available and 2020 is the end of the projections.

When observing the net emissions for 1995 and 2008 according to the baseline scenario, it is obvious that there is an impressive decrease even if future developments follow business-as-usual projections. Already in 2008, when the latest reported data are available, net emissions have been reduced by more than 2.3 times compared to GHG emissions emitted in 1995 (factor 2.4 since 1990). In the same time period, the recycling share has increased by 2.4 times (factor 3 since 1990). The correlation of emissions to recycling share is not legitimate as emissions are not formed by developments in recycling only, but the relevance of the recycling share is nonetheless demonstrated.

Figure 1.5 GHG emissions results according to each future scenario



The results show that the unexploited potential for global warming mitigation is quite significant. Table 1.2 shows how the different components of MSW management contribute to this effect.

In the baseline scenario, direct emissions are lower than in the Landfill Ban scenario, because of the time delay of methane emissions: the reduction of landfilled quantities leads to increased direct emissions from recycling, incineration and waste transport that appear immediately, while the reduction of the direct emissions from landfilling remain high as they strongly depend on waste landfilled prior to the landfill ban. After a period of time, the effects of the actions against landfilling would appear on the direct emissions, but this analysis is outside the time scope of this study.

On the other hand, the effects of these actions appear instantly on the avoided emissions' side, as these are linked mainly to the benefits from recycling but also from incineration. Therefore, in spite of the higher direct emissions of the Landfill Ban scenario, the absolute increase in the avoided emissions leads to an almost 34 million tonnes of CO_2-equivalents difference with the baseline scenario.

Table 1.2 Comparison of simulated scenarios in terms of direct and avoided emissions in 1990, 1995, 2008 and 2020.

Year	Direct emissions (Mt of CO_2-eq)	Avoided emissions (Mt of CO_2-eq)	Net emissions (Mt of CO_2-eq)

1990	103.79	-27.41	76.38
1995	121.3	-37.54	83.75
2008	129.17	-93.34	35.82
2020 Baseline	112.53	-120.73	-8.20
2020 Landfill Directive	111.06	-137.54	-26.49
2020 Landfill Ban	123,82	-165,63	-41,81

2. Introduction

The Sixth Environmental Action Programme (2002-2012) sets out key environmental objectives to be attained. One of the overall aims is to decouple the use of resources and the generation of waste from the rate of economic growth (Article 2).

On the sustainable use and management of natural resources and wastes, the programme aims at (Article 8):

- a significant, overall reduction in the volumes of waste generated through waste prevention initiatives, better resource efficiency and a shift towards more sustainable production and consumption patterns;
- a significant reduction in the quantity of waste going to disposal and the volumes of hazardous waste produced;
- encouraging re-use, and for wastes that are still generated:
    - the level of their hazardousness should be reduced and they should present as little risk as possible;
    - preference should be given to recovery and especially to recycling;
    - the quantity of waste for disposal should be minimised and should be safely disposed of;
    - waste intended for disposal should be treated as closely as possible to the place of its generation, to the extent that this does not lead to a decrease in the efficiency in waste treatment operations.

The Thematic Strategy on Prevention and Recycling of Waste stated that ‘The long-term goal is for the EU to become a recycling society that seeks to avoid waste and uses waste as a resource. With high environmental reference standards in place the internal market will facilitate recycling and recovery activities.’ (European Commission, 2005b)

The amended Waste Framework Directive (2008/98/EC) includes new recycling targets on waste from households and construction and demolition waste and says in its preamble 28 that the Directive should help move the EU closer to a ‘recycling society’, seeking to avoid waste generation and to use waste as a resource. Before 2008, the Packaging and Packaging Waste Directive of 1994 and 2004 created incentives for recycling MSW as well since a great part of packaging waste can be found in the municipal waste stream. Further, the Landfill Directive (99/31/EC) has set targets for the level of biodegradable MSW that is allowed to be landfilled according to a specific timetable.

In order to study the likely future trends in European waste management, the EEA and the European Topic Centre on Sustainable Consumption and Production have developed a model for the projection of waste quantities and estimation of the management as well as greenhouse gas emissions associated with this management. At present, the model covers the municipal waste and construction and demolition waste streams. This working paper refers to municipal waste.

The projections have been made for the 27 EU Member States, Norway and Switzerland. The original aim was to include all member countries of the European Environment Agency, but only for Norway and Switzerland sufficient data for this analysis was available. In this report the term “EU-27” refers to the 26 included EU Member States plus Norway and Switzerland; Cyprus is excluded because of lack of data. However, as the focus is on the trends in the entire EU, **aggregated** data for the EU-27 countries, and for two country groupings are presented: 15 Member States (EU-15) that consist of Austria, Belgium, Denmark, France, Finland, Germany, Greece, Italy, Ireland, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK plus Norway and Switzerland and the 12 Member States (EU-12), which are Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia, excluding Cyprus. The trends in the EU-15 + Norway and Switzerland and EU-12 Member States vary considerably which is the main reason for showing results for both the EU-15 + Norway and Switzerland and EU-12.

Greenhouse gas emissions have been chosen as the environmental pressure indicator because they represent a sizeable environmental effect from the management of municipal waste. Because climate change is an extremely urgent topic on the political agenda we concentrate on this parameter, but from a broader environmental perspective. Other pressures such as emissions of particles, nitrogen oxide or dangerous substances cause different environmental effects which should not be neglected. The representativeness of GHG emissions and the corresponding global warming potential as an environmental indicator to assess the performance of a system can often be limited (Merrild, 2009).

The GHG direct emissions from municipal waste management consist mainly of methane emissions from landfill and energy-related GHG emissions from the collection and management of waste. There are also avoided GHG emissions from energy consumption due to recycling of secondary materials compared to the production of virgin materials, incineration or the use of collected landfill gas for energy recovery. Life-cycle information allows a calculation to be made of these avoided emissions that represent the benefit of recycling for manufacturing materials and for incineration or landfilling producing energy instead of using fossil fuels and virgin materials. At least 50 to 60 % of MSW consists of materials of biogenic origin (like food and garden waste, wood, paper and cardboard and partly textiles). Because of the assumption that biogenic CO2 emissions are climate-neutral, CO2 emissions from waste incineration plants, measured per produced energy unit, are much lower than from a fossil fuel-fired power plant.

The EU-15 agreed under the Kyoto Protocol to an 8% reduction in total greenhouse gas emissions by 2008-2012 from 1990 levels, and EU-12 Member States have individual reduction targets. For reference, in 2007 the **direct** greenhouse gas emissions from waste management represented 2.6% of the total emissions in the EU-15. This only includes the direct emissions from landfills, anaerobic digestion plants and incineration without energy recovery but not recycling and incineration with energy recovery, which are reported in other sectors under the United Nations Framework Convention on Climate Change (UNFCCC).

The projections have been made for the period 2009-2030, but only the projections till 2020 are presented here. The reason is that the projections beyond 2020 become highly uncertain.

2.1. Changes in the model since the previous working paper

The model of municipal waste management and greenhouse gas emissions is continually being improved and revised by the ETC/SCP. The first official publication of results was in the form of an EEA briefing in January 2008, with a working paper published simultaneously on the Topic Centre's website. Since then, updated datasets have become available and the ETC/SCP has improved the modelling in several respects. The main changes since the previous working paper are:

- Data on *MSW generated* have been updated with reported 2008 data, and the projections have been recalculated taking into account an updated *economic forecast* from the European Commission (August 2010) which incorporates the *effects of the economic crisis*. The projected amount of waste generated in the EU-27 + Norway and Switzerland in 2020 is then altered from the previous projection of 335 million tonnes, to 279 million tonnes in the new scenario that accounts for the effects of the crisis.
- Data on *MSW management,* i.e. the percentages of waste going to landfill, incineration and recycling, have been updated to 2008 data, and the projections of these have been updated accordingly. In many countries, the reduction in landfill-

ing is happening faster than expected in the previous version of the model. Here, the estimated landfill rate was 34% in 2020, whereas the new estimations give a figure of only 28% in 2020.

- The *composition of the recycled waste* has been revised for several countries using newly collected data from another ETC/SCP project (ETC/SCP, 2009).
- The *methane recovery rates* have been revised in order to reflect the latest scientific findings and bridge the gap between the IPCC Guidelines proposed value and the countries' individual reporting to UNFCCC.
- *GWP factors* are updated to the 2007 IPCC values (see table 6.1). This means that methane emissions are weighted higher when converted to CO_2-equivalents, and this affects mainly the direct emissions from landfills.
- The *emissions from electricity production* saved by recovering landfill gas and incinerating waste have been revised to reflect national energy mixes instead of an EU-27 mix. This influences the avoided emissions from landfilling and incineration, and for some countries they are higher, for some countries lower.
- The *kitchen and garden waste(bio-waste) management* has been updated. There are now three options involved in the treatment of bio-waste, namely composting, home composting and anaerobic digestion. The new results are more conservative as they show lower benefits than the old configuration of the model (see chapter 4.4).

The three latter changes in the calculation of emissions have a direct impact on the results, but the change in waste amounts, composition, management and methane recovery rates also affect the GHG balance. The reduced amount of waste generated in the future – due to lower economic growth compared to the baseline that had been used prior to the economic crisis, i.e. in the EEA briefing 1/2008, results both in lower direct emissions (less waste going to landfill) and in lower avoided emissions (less energy and material saving from recycling – no significant change for incineration). As a consequence, the impact of waste management on total net emissions is reduced compared to the EEA briefing's results. The change in composition of the recycled waste may have affected the results in both directions, since the benefits of recycling vary from one fraction to another. As the recycling level in the EU is high in general, this can affect the results significantly. The general increase of methane recovery rates in landfills leads to an increase of the recovered energy, which substitutes primary energy production based usually on fossil fuels. Therefore, the benefits for the waste management system increase correspondingly with the higher avoided emissions. The summary of the changes as well as their impact on waste arisings and associated GHG emissions can be seen in table 2.1.

Table 2.1 Effect of changes on generated waste quantities and overall net GHG emissions.[3]

Parameter	Description of change	Effect on waste quantities	Effect on GHG emissions
Economic projections	Economic crisis	↑	↓
Treatment shares	Less landfilling and more recycling	Not relevant	↑↑
Composition of recyclables	More country-specific information	Not relevant	↑
Methane recovery rates	Corrected after consulting experts	Not relevant	↑↑↑
GWP factors	Updated according to the revised IPCC values	Not relevant	↓
Replaced energy mix	Country-specific energy mix	Not relevant	+
Bio-waste management	More treatment options	Not relevant	-

3 + indicates a positive effect (reduction of quantities or reduction of net emissions) while - indicates a negative effect (increase of quantities or increase of net emissions).

3. Projection of municipal waste

3.1. Model parameters for municipal waste

The description of the projections model, along with the assumptions for the parameters can be found in Annex IV. In this chapter, the actual model parameters used are shown as well as the data sources.

The projections mainly use the population and the final private consumption of three categories (food, beverages, and clothing) as explanatory variables. The model parameters are shown in Tables 3.1 and 3.2 (see annex IV for further details). The trend-wise annual changes in the amount of waste, a_{i3}, are phased out after 5 years for all countries.

Table 3.1 Model parameters for municipal waste in EU-15 , Norway and Switzerland

Country	No of obs.	Act. Var.	Constant α_0	Activity α_1	Household α_2	Trend τ	Dummy δ	Dummy δ_1	R^2	DW
AT	12	detail	-1.809	0.359	$1-\alpha 1$	0.014	-0.157		0.96	1.04
			(2,44)	(1,04)	–	(0,004)	(0,03)			
BE	12	detail	-0.757	0.462	$1-\alpha 1$		-0.036		0.83	1.89
			(0,25)	(0,13)	–		(0,02)			
DE	12	detail	-0.681	1	–	-0.009	0.008	0.050	0.87	1.55
			(0,39)	-	–	(0,004)	(0,03)	(0,02)		
DK	12	detail	-1.739	0.531	$1-\alpha 1$	0.011	-0.044		0.94	2.58
			(0,51)	(0,52)	–	(0,009)	(0,04)			
FI	12	detail	-0.775	0.423	$1-\alpha 1$		0.104		0.86	0.88
			(0,38)	(0,20)	–		(0,02)			
FR	12	detail	-2,559	1	–	0,009			0.98	1.59
			(0,09)	-	–	(0,001)				
ES	12	detail	-0.054	1	–	-0.011	-0.134		0.89	1.30
			(0,55)	-	–	(0,005)	(0,04)			
GR	12	detail	-1.724	0.977	–	-	-0.157		0.92	1.42
			(0,85)	(0,44)	–	-	(0,05)			
IE	12	detail	-0.932	0.633	$1-\alpha 1$		-0.170		0.98	1.85
		/pop	(0,15)	(0,15)	–		(0,03)			
IT	12	detail	-1.658	0.488	$1-\alpha 1$	0.010	0.008		0.97	2.14
			(0,91)	(0,30)	–	(0,004)	(0,02)			
LU	12	detail	-1.253	0.271	$1-\alpha 1$	0.011			0.94	1.63
			(0,39)	(0,13)	–	(0,003)				
NL	14	detail	-1.395	0.942	$1-\alpha 1$				0.96	1.51
			(0,23)	(0,13)	–					
PT	9	detail	-1.131	0.777	$1-\alpha 1$		0.075		0.97	1.23
			(0,19)	(0,11)	–		(0,02)			
SE	12	detail	-1.181	0.648	$1-\alpha 1$		-0.104		0.95	1.88
			(0,37)	(0,21)	–		(0,02)			
UK	12	detail	-0.337	0.348	$1-\alpha 1$		-0.021	0.050	0.97	1.22
			(0,22)	(0,12)	–		(0,04)	(0,02)		
NO	11	detail	-1.927	1	-	0.0015	0.0947		0.967	1.848
			(0.33)	-	-	(0,003)	(0,02)			
CH	12	detail	-1.826	0.3135	1-a1	0.0096	-0.0338		0.955	2.223
			(0,99)	(0,75)		(0,003)	(0,03)			

Table 3.2 Model parameters for municipal waste, EU-12, excl Cyprus

Country	No of obs.	Act. Var.	Constant α_0	Activity α_1	Household α_2	Trend τ	Dummy δ	Dummy δ_1	R^2	DW
BG no act data	12	pop	0,826	-	1	-0,015	0,160		0,93	1,26
			(0,59)	-	–	(0,006)	(0,05)			
CY	12	aggr.	-2,310	0,844	1−α1				0,93	1,00
		pop	(0,33)	(0,14)	–					
CZ	12	detail	-0,697	0,413	1−α1		0,216		0,87	2,32
			(0,17)	(0,19)	–		(0,02)			
EE	12	detail	-0,28	0,50	1−α1		0,11		0,63	1,80
			(0,11)	(0,14)	–		(0,05)			
HU	12	aggr.	-0,086	0,149	1−α1		0,107	0,015	0,87	2,25
			(0,17)	(0,09)	–		(0,03)	(0,02)		
LT	11	aggr.	-0,256	0,197	1−α1		0,303	0,098	0,90	2,44
			(0,22)	(0,13)	–		(0,07)	(0,04)		
LV	7	aggr.	-1,712	0,908	1−α1		0,211		0,71	0,92
			(0,16)	(0,27)	–		(0,10)			
MT	12	aggr.	-5,661	0,578	1−α1	0,045	-0,171		0,99	2,70
			(0,32)	(0,21)	–	(0,007)	(0,03)			
PL	12	aggr.	-0,869	0,300	1−α1		0,295	0,142	0,91	2,58
			(0,29)	(0,14)	–		(0,04)	(0,03)		
SI	12	detail	1,865	1	–	-0,032	0,231	0,071	0,91	1,14
			(1,07)	-	–	(0,01)	(0,07)	(0,07)		
SK	10	detail	-1,936	0,529	1−α1	0,014	-0,010		0,77	1,16
			(0,51)	(0,29)	–	(0,005)	(0,05)			
RO	8	aggr.	-0,416	0,367	1−α1		0,100		0,55	2,89
			(0,18)	(0,14)	–		(0,06)			

Where:
No. of obs.: Number of observations
Act. Var.: Activity variation
Activity: parameter describing the elasticity of MSW with respect to the household's economic activities' level
Household: parameter describing the elasticity of MSW with respect to population level
Trend: parameter describing the historical trends of MSW generation associated with time
Dummy: random dummies used for calibrating the model
R^2: coefficient of determination
DW: the Durbin–Watson test parameter

3.2. Data sources

The per capita municipal waste generation for the periods 1990-1994 and 2009-2020 are estimated on the basis of different assumptions. Data for the period 1995-2008 stem from Eurostat. The method of estimation or source of data is presented in Table 3.3.

The projections of municipal waste generation until 2020 are based on the development of GDP. The GDP projections were published by DG Energy of the European Commission individually for each country (DG ENER, 2010).

Table 3.3 Generation of municipal waste, method of estimation and source of data

	Method	Comment/source
1990-1994	Estimation of municipal waste generation per capita based on the development in GDP.	GDP data is based on information from the 'annual macroeconomic database' (AMECO) from the European Commission (hosted by DG ECFIN). For the EU-12 data are only available from 1991, and as a result for 1990 a constant growth of 1.5% is assumed. Private final consumption: Eurostat Population: Eurostat/UN
1995-2008	Structural Indicators: Generation of municipal waste generation per capita	Structural Indicators published by Eurostat Private final consumption and population: Eurostat (http://epp.eurostat.ec.europa.eu/portal/page/portal/national_accounts/data/database, http://epp.eurostat.ec.europa.eu/portal/page/portal/population/data/database)
2009-2030	Estimation of municipal waste generation per capita	Projections of municipal waste (results from the ETC projections model) Population: European Commission

4. Modelling management of municipal waste

The point of departure for the assumptions for municipal waste management in Europe is Eurostat's Structural Indicators on municipal waste generation, landfill and incineration for the period 1995-2008[4]. In this section, we present the assumptions made for waste management during the entire modelling period, 1990-2020.

A general assumption which is common for all treatment options is that the future projection of the quantities landfilled/incinerated/recycled is based on historical trends and planned policy measures. More explicitly, the historical trends, regarding the ranking of preferred treatment options for each country and the development of their shares over time, are analysed based on the Structural Indicator data. This trend is projected in the future for the period 2009-2020. In this way, the particularities of each country and national strategies on MSW management are maintained for the projections as they appear in the historical data. These treatment share projections are then calibrated in order to shift the focus on landfilling avoidance and increased recycling. This calibration happens in order for the projections to take into account the planned or existing EU legislation which promotes recycling (e.g. Waste Framework Directive) or discourages landfilling (e.g. Landfill Directive).

In the baseline scenario, the implementation of EU legislation is not considered to be mandatory for the MS. More gravity is given to the continuation of the current historically developed trends. The baseline thus takes into account that the Landfill Directive might not be fully implemented in all countries. Generally, the specific treatment options' shares are estimated for each country following the ETC/SCP expert judgement on utilising the aforementioned assumptions, namely no formula has been used for the treatment shares' projections. For the shares assumed for each country, please see Annex.

4.1. Landfilling of municipal waste

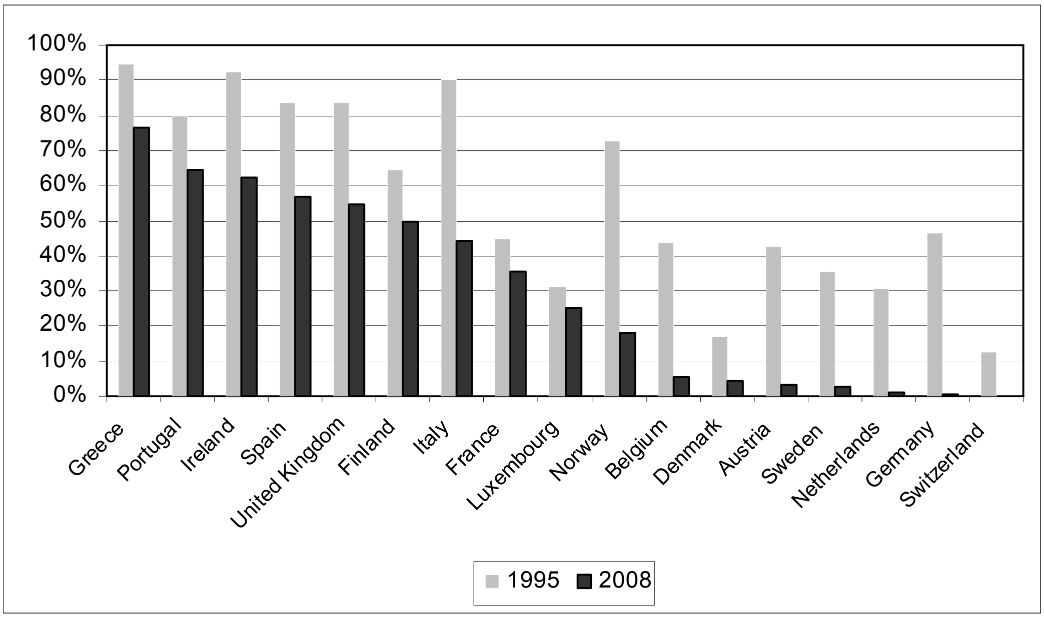
4.1.1. Observed changes

Landfill of municipal waste has been the predominant option in the EU-27 + Norway and Switzerland for several years but this is changing. In 1995 the average landfill rate was 68% but in 2008 this had fallen to 40%. However, waste management practises vary greatly among the member States.

Twelve of the EU-15 + Norway and Switzerland Member States landfilled less than 50% of the municipal waste in 2008 (Figure 4.1), while the majority of the EU-12 Member States landfilled just around 90% (Figure 4.2). The figures also show that in several countries considerable reductions in the landfill of waste have taken place over the 13-year period. However, in some EU-12 countries the trend is opposite. There is no clear answer as to why this is happening, but possible explanations are factors such as the introduction of better statistical methods or the break down of former existing recycling systems etc.

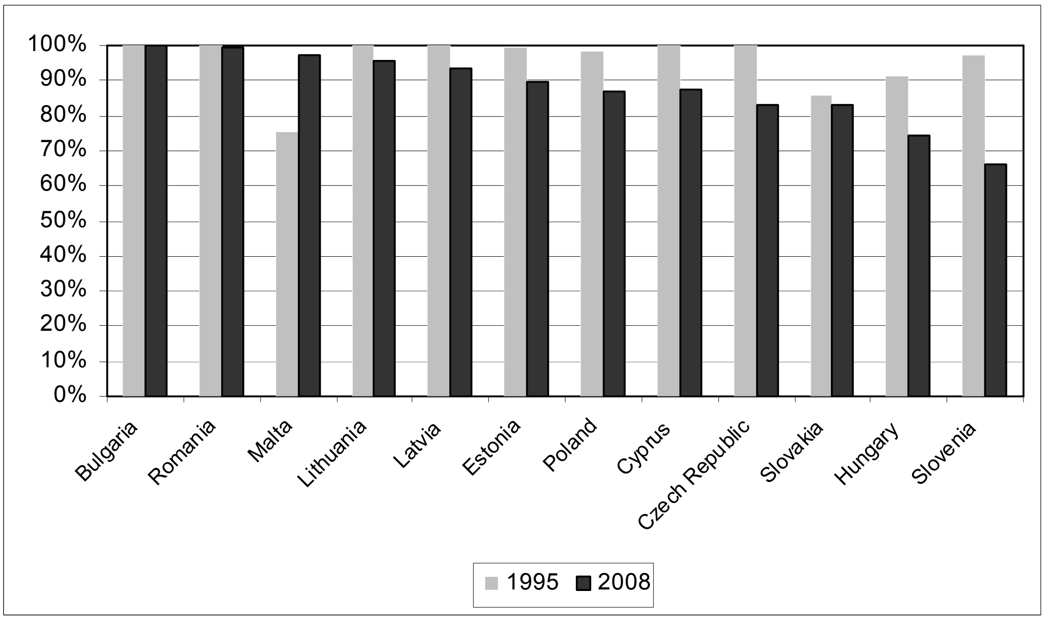
[4] The projection starts in 2009

Figure 4.1 Landfill of municipal waste in the EU-15, Norway and Switzerland, 1995 and 2008



Source: Calculated based on Eurostat Structural Indicator data

Figure 4.2 Landfill of municipal waste in the EU-12 (excl. Cyprus), 1995 and 2008



Source: Calculated based on Eurostat Structural Indicator data

4.1.2. Assumptions for the estimation

In order to estimate the amount of municipal waste landfilled during the 30-year period 1990 to 2020, a series of assumptions has been made. The landfill rates are calculated as the amount of landfilled waste over the amount of generated waste.

Between 1990 and 1994, the landfill rate has been interpolated to reach the landfill rate in 1995. This was necessary, since the Eurostat data only covers the period from 1995. The interpolation begins in 1965 and gradually reaches the value reported to Eurostat for 1995. The assumption is that all countries landfilled all MSW until 1964. Therefore, the interpolation begins then, although the years prior to 1990 are outside the scope of this project.

Between 1995 and 2008, Eurostat Structural Indicator data have been used.

The projected landfilling of waste from 2009 to 2020 is a ‘best estimate’ made by the ETC/SCP, taking into account historical trends and the implementation of relevant policy measures to divert waste from landfill. The historical trends as they appear in the Eurostat data until 2008 give an impression of the direction that MSW management will follow in each country for the period 2009-2020. These trends could, in principle, be extended until 2020 but for the fact that Landfill Directive targets fulfilled during the projection period should be taken into account. Therefore, the extended historical trends are calibrated based on the incentives for countries to divert waste from landfill according to the mandate from the Directive. The landfill rates applied in the baseline projection are presented in Annex III.

No further assumptions have been made beyond 2020.

The types of landfills included are (IPCC, 2006):

- Managed Solid Waste Disposal Sites,
- Unmanaged Solid Waste Disposal Sites (open dumps, including above-ground piles, holes in the ground and dumping into natural features such as ravines).

Section 5.3 presents further information about the assumed development in landfill types.

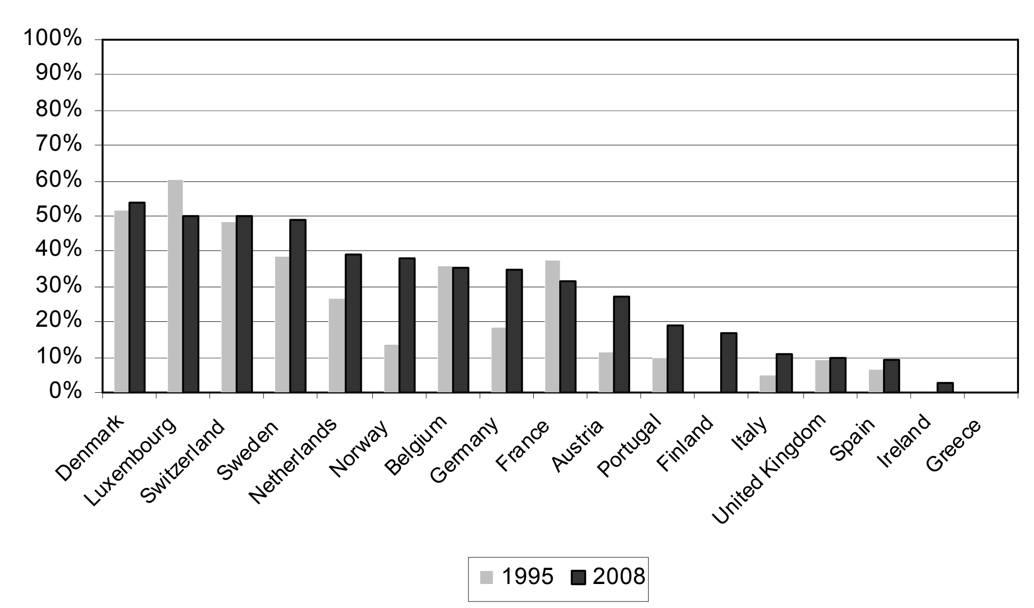
4.2. Incineration of municipal waste

It is assumed that all incineration takes place with energy recovery (see section 10.2.1 for more details). Despite the fact that the parameters referring to incineration plants (efficiency, dry/semi-dry method etc) varies from country to country, a default plant is simulated to the model, as more detailed national data do not exist.

4.2.1. Observed changes

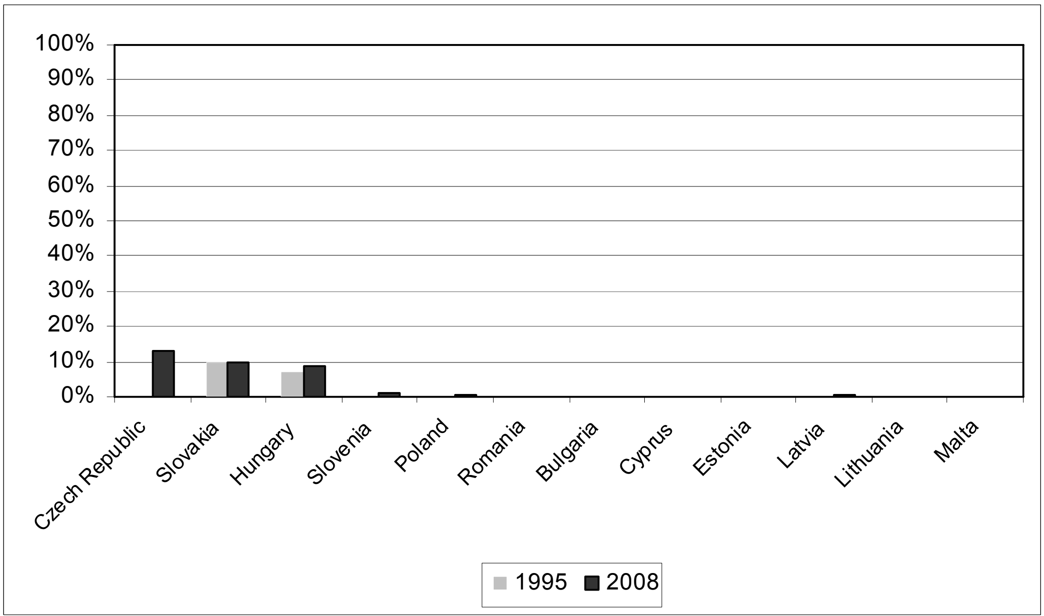
The incineration rates in 1995 and 2008 are shown in Figure 4.3 and 4.4. Three of the EU-15 + Norway and Switzerland countries and eleven of the EU-12 countries had either no incineration or incinerated less than 10% of the generated waste in 2008. Ten countries incinerated more than 20% of the municipal waste in 2008.

Figure 4.3 Incineration of municipal waste in the EU-15, Norway and Switzerland, 1995 and 2008



Source: Calculated based on Eurostat Structural Indicator data

Figure 4.4 Incineration of municipal waste in the EU-12 (excl Cyprus), 1995 and 2008



Source: Calculated based on Eurostat Structural Indicator data

4.2.2. Assumptions for the estimation

The estimates of municipal waste incinerated are calculated as a share of municipal waste generated.

Between 1990 and 1994, the incineration rate has been interpolated to reach the calculated incineration rate in 1995. This was necessary, since the Eurostat data only covers the period from 1995. The interpolation begins in 1965 and gradually reaches the value reported to Eurostat for 1995. The assumption is that no country incinerated any MSW until 1964. Therefore, the interpolation begins then, although the years prior to 1990 are outside the scope of this project.

Between 1995 and 2008, Eurostat Structural Indicator data have been used.

The projected incineration of waste from 2009 to 2020 is a ‘best estimate’ made by the ETC/SCP, taking into account historical trends and the implementation of policy measures. As in the landfilling part, the historical trends are extended for the projection period. However, the influence of existing legislation is also taken into account. There is no target for the incineration of MSW but since MSW quantities are diverted away from the landfills (Landfill Directive) more MSW would normally be available for incineration. There is a strong incentive, though, for these extra quantities to be recycled based on the targets of the revised Waste Framework Directive. Therefore, the percentage of MSW incinerated should not present significant variations for the projection years 2009-2020. The assumptions regarding projections are also based on incineration plants planned or under construction. The incineration rates applied in the baseline projection are presented in Annex III.

No further assumptions have been made beyond 2020.

For further information on emissions from incineration, see section 5.4.

4.3. Recycling of municipal waste

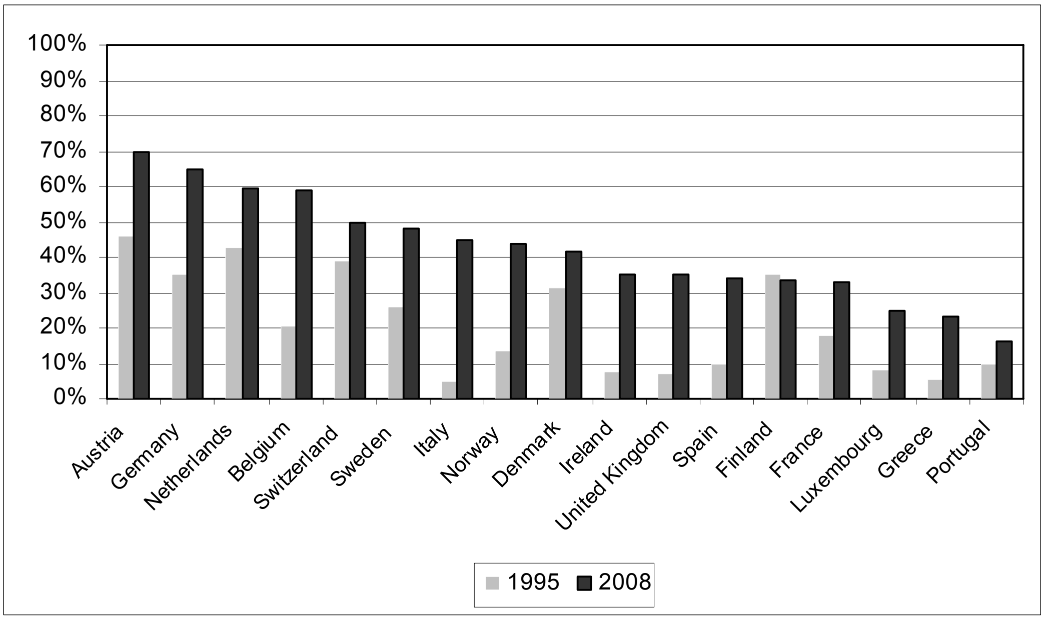
4.3.1. Observed changes

The Structural Indicators published by Eurostat include recycling of municipal waste from 1995 to 2008. The information available at Eurostat presents problems for some countries, since the sum of all treatment options does not equal the generated amounts for the same year. The reported data, when this problem occurs, are deduced so that the equation Generation = Landfilling + Recycling + Composting + Incineration is fulfilled. This can happen by increasing respectively the figures reported for each of the treatment options.

For the remaining years, we have estimated the recycling rate as the residual of generation once landfill and incineration are subtracted. This is a simplification and the estimated recycling rate may therefore include activities that are not considered as recycling but rather recovery or even unknown (landfill or ‘export’ or other treatment methods like mechanical-biological treatment). For some countries where additional information was available, e.g. from national reports, the calculated recycling rates are probably a little too high and in these cases the recycling rate has been corrected downwards.

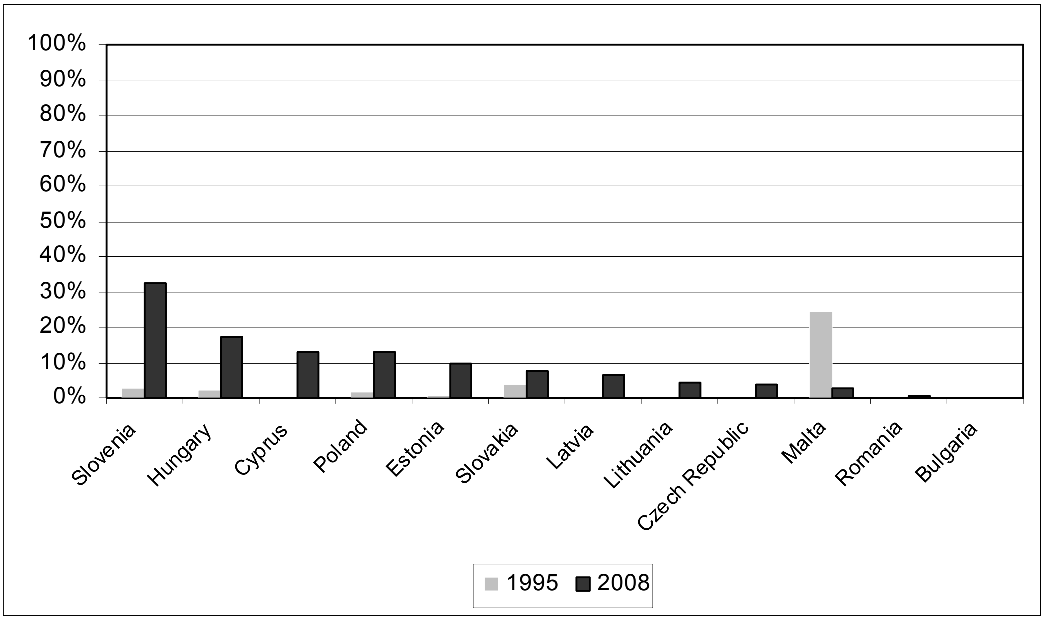
Figures 4.5 and 4.6 show that the recycling rates have increased for most countries from 1995 to 2008. Four EU-15 + Norway and Switzerland countries recycled more than 50% in 2008 and most of the remaining countries recycled between 30% and 50%. The recycling rates in the EU-12 vary from approximately 5% to 35%.

Figure 4.5 Recycling of municipal waste in the EU-15, Norway and Switzerland, 1995-2008



Note: 1995: The recycling rate is estimated as the residual of generation once landfill and incineration are subtracted. 2008: Recycling and composting data from Eurostat

Figure 4.6 Recycling of municipal waste in the EU-12, 1995-2008



Note: 1995: The recycling rate is estimated as the residual of generation once landfill and incineration are subtracted. 2008: Recycling and composting data from Eurostat

4.3.2. Assumptions for the estimation

During the period 1995-2008, Eurostat data are used for recycling. Throughout the **estimation** period (1990-1994 and 2009-2020), recycling is calculated as waste generation minus landfilled and incinerated waste, namely the landfill and incineration shares are first estimated and the remaining quantity is assumed to be recycled.

Recycling comprises the recycling of the following fractions: food and garden waste, paper, glass, metals, plastics, textiles and wood. Comparable data for recycling of these fractions are scarce which is why we have chosen a relatively simple approach.

The data on total recycling of food and garden waste are extracted from Eurostat for the period 1995-2008 (under the title “municipal waste composted”) and are extrapolated in the other years in question. An average composting rate is estimated and expressed as a percentage of the overall recycling of all fractions in the historical data (share of composted MSW in all recycled MSW). This percentage of composting as a share of the overall recycling is assumed constant for 1990-1994 and 2009-2020. Therefore, the composting *quantities* fluctuate according to the developments in recycling of all MSW.

The recycling of materials other than food and garden waste is calculated as a percentage of the fraction recycled (total recycling rate – composting rate). Table 4.1 shows an average waste composition of the recycled waste. These figures are based on data for five countries, namely Austria, Belgium, Denmark, Sweden and UK. This distribution of the recycled waste fractions is kept constant throughout the projection period.

Table 4.1 Recycling of waste fractions in % of total recycling rate

Composting	Paper & cardboard	Plastic	Glass	Metals	Wood	Textiles
Eurostat data 1995 – 2003, average of five countries	50%	9.70%	14.50%	9.70%	14.50%	1.60%

As a part of another project, the ETC/SCP has gathered further information for some countries by national statistical offices and EPAs (ETC/SCP, 2009). These new datasets orientate mostly on clarifying the composition of the recyclable fraction excluding composting. In the cases where new data is available, we have sought to replace the data in the above table with an average national composition. Nonetheless, these collected datasets cover only parts of the time interval between 1995 and 2007 and for a limited number of countries (ETC/SCP, 2009). Furthermore, parts of the waste are not classified according to the abovementioned fractions, and it has been necessary to adjust the figures. Hence, the textile fraction is set to 1.6% as in Table 4.1, and the remaining non-classified waste has been redistributed to the other five fractions with respect to their percentage of the total recyclables.

For the countries where no data on the composition was available (i.e. Bulgaria, France, Greece, Hungary, Latvia, Malta, Portugal, Romania, Slovakia, Slovenia), we have used the default values of Table 4.1.

4.4. Recycling of food and garden waste

The estimated total quantities for the recycling of food and garden waste are distributed into specific treatment options; home composting, central composting and anaerobic digestion. This happens according to the estimates included in the recently released impact assessment study (Annex A) by the European Commission on the “Assessment of the options to improve the management of bio-waste in the European Union” (EC, 2010). This study refers to bio-waste which also includes other organic fractions, besides food and garden wastes. However, the same distribution is assumed for food and garden waste since the treatment distribution is assumed identical to bio-waste and there is no better data available.

The EC study only covers the period 2008-2020 and only the EU Member States, thus there is a need for further assumptions. The distribution for 1990-2007 is back casted from the 2008 data according to the following principles:

1. No anaerobic digestion is assumed before 2000, so the digested quantities are linearly reduced to 0 from 2008 to 2000.
2. The ratio between composting and home composting is stable. This means that the reduction in digested quantities is equally distributed to the other options.

3. For countries where no anaerobic digestion takes place, the composting and home composting shares are kept constant for the back casting.

The treatment distribution for Norway is estimated based on information from www.avfallnorge.no.

The assumptions for Switzerland are based on information from the Federal Office for the Environment, Waste and Raw Materials Division (http://www.bafu.admin.ch/abfall/index.html?lang=en). In 2008, 930000 tonnes of compostable waste were collected. Since the anaerobic digestion capacity for all waste streams (including industrial waste) is 250000 tonnes in 2010, 100000 tonnes of municipal food and garden waste is assumed to undergo anaerobic digestion in 2008, i.e. 11% of compostable waste collected. This percentage rises to 20% by 2020 linearly and is reduced to 0 by 2000. The home composting is low and assumed to be 5% for the entire period 1990-2020, while the remaining quantity is composted centrally.

5. Modelling greenhouse gas emissions

The following sections describe the methodology used to model the greenhouse gas (GHG) emissions from the treatment of municipal waste. The baseline scenario includes assumptions regarding the composition of municipal waste; direct emissions from landfill sites, incineration and recycling plants; and the benefits from recovery of landfill gas, incineration and recycling of waste. We use the following terms to describe the emissions.

Net emissions = direct emissions - avoided emissions

Direct emissions: The emissions that occur as a direct consequence of the waste management, including for example methane from landfills, carbon dioxide from the incineration of waste and emissions from the energy used for recycling.

Avoided emissions: The emissions that are avoided as an indirect consequence of waste management, including for example emissions from energy production from other fuels than waste and emissions related to the production of primary materials.

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* are the methodologies adopted by the UNFCCC for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases. This includes in particular greenhouse gas emissions from waste management (landfilling and incineration). Following revision of these guidelines, the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) include new sources and gases as well as updates to the previously published methods whenever scientific and technical knowledge have improved since the previous guidelines were issued. On the basis of these guidelines, EU Member States report the composition of waste and emissions from landfilling and incineration as part of their GHG inventory report submitted annually to the UNFCCC.

We have modelled the emissions from landfilling, incineration and recycling using the following principles:

1. Landfilling: Follows the 2006 IPCC guideline. Emissions are calculated on the basis of a carbon mass balance. Methane recovery rates are estimated on the basis of the Member States' reports to the UNFCCC and the proposed value in the 2006 IPCC guidelines.
2. Incineration: Emissions are calculated on the basis of a carbon mass balance, as suggested by the 2006 IPCC guideline, but is further specified in the model for all combusted materials (and not only an average of the mixed waste).
3. Recycling: Calculation of emissions is based on life cycle data collected in a previous ETC/RWM study on environmental impacts from the treatment of specific waste streams (ETC/RWM, 2006) combined with data from Danish and European life cycle assessment databases.
4. Avoided emissions: All savings per kg due to material or energy recovery are calculated on the basis of life cycle data from the same sources as for the recycling.

5.1. Greenhouse gas emissions as environmental indicator

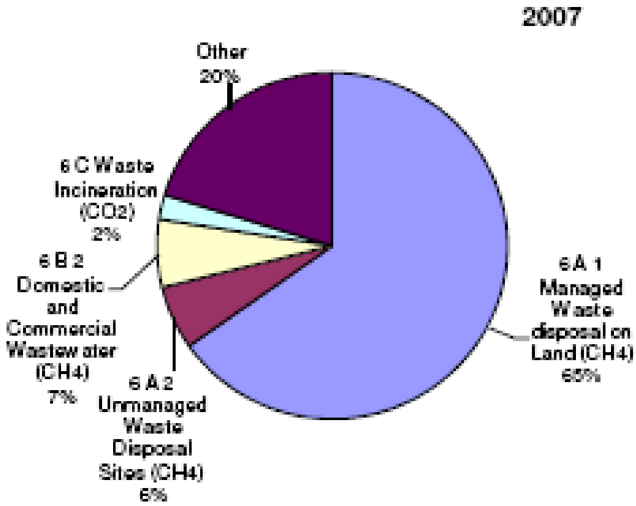
We have chosen to focus on GHG emissions in this study for political, environmental as well as methodological reasons. Climate change is very high on the international political agenda as the scientific proof of the human impact on climate change becomes stronger (see for example IPCC, 2007) and as society is becoming aware of the potential consequences of climate change. Therefore, the GHG emissions resulting from waste management are of high interest.

Moreover, GHG emissions could function as an environmental indicator in order to assess the overall performance of the MSW management system. However, the representativeness of this indicator is questionable, although it presents significant benefits (Merrild et al, 2009).

The methodological considerations regarding the choice of environmental indicators are related to data availability and reliability. The method for calculating GHG emissions is rather simple (in this study mainly simple mass balances) and GHG emissions are always included in life cycle data. Moreover, there is scientific agreement on the cause-effect relations of GHG and climate change.

The greenhouse gases covered in the IPCC reporting are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and fluorinated gases (HFCs, PFCs and SF6). The first three are the main contributors from the waste sector. The key sources of greenhouse gas in the waste sector, as it is defined in the IPCC reporting, are illustrated in Figure 6.1 below.

Figure 5.1 Direct greenhouse gas emissions from the waste sector in the EU-15, 2007[5]



Source: EEA (2009)

Figure 5.1 shows that CH_4 emissions from landfills account for 75% of the waste-related greenhouse gas emissions in the EU-15 (excl CH and NO). According to the EC GHG inventory report (EEA 2007), this percentage is larger in the EU-12 (excl BG and RO) due to larger use of landfilling for waste disposal in these countries compared to the EU-15.

In addition to CH_4, landfills also produce biogenic CO_2 and non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of N_2O, NO_x and CO. Decomposition of organic material derived from biomass sources (e.g. crops, wood) is the primary source of CO_2 released from waste. These CO_2 emissions are not included in inventories, be-

[5] The waste sector is defined in the IPCC reporting as landfilling, composting and aerobic digestion in biogas facilities, incineration without energy recovery and waste water treatment. In IPCCC reporting recycling facilities are included in the industrial sector and incineration with energy recovery in the energy sector.

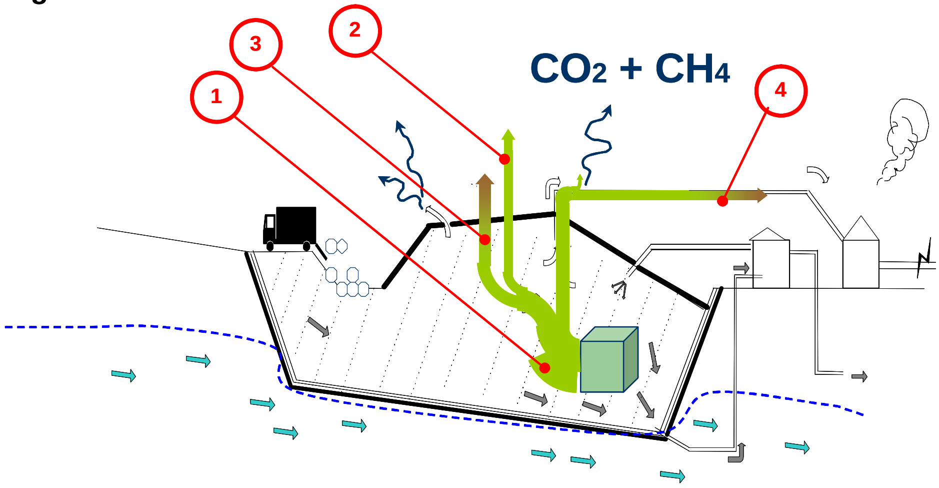
cause the carbon is of biogenic origin and it is therefore assumed that they stem from the uptake of atmospheric CO_2.

In contrast to GHG inventories reported under the UNFCCC, the ETC/SCP model includes all carbon inputs and outputs, be these biogenic or anthropogenic (biogenic emissions are defined as emissions originating from biomass release of sequestered carbon).Therefore, the model's results can be presented either including biogenic emissions or excluding them. In order to align with the general scientific consensus, the biogenic emissions are not included in the results presented in this working paper. In order to ensure that all carbon inputs and outputs are included, the model is based on a carbon mass balance. In a landfill, for instance, one can distinguish four sources of carbon emissions:

1 Direct emission of CO_2 from anaerobic biodegradation
2 Direct emission of CH_4 from anaerobic biodegradation
3 Emission of CO_2 from CH_4 oxidised in the top layers
4 Emission of CO_2 from recovered CH_4 which is oxidised by flaring (with or without energy generation).

Emissions 1 and 3 are biogenic and thus not included in the model. These four sources are illustrated in Figure 5.2. No methodology is provided for N_2O emissions from landfills due to their small significance.

Figure 5.2 Sources of carbon emissions in a landfill



Methane emissions from landfills have a singular characteristic compared to aerobic greenhouse gas emissions. Contrary to greenhouse gas emissions from waste incinerators and composting plants, landfill greenhouse gas emissions are characterised by the large time lag of emissions. Biodegradable waste landfilled today may start gas production next year, reach a peak in 4-10 year's time, and prolong its production for up to 50-60 years. Modelling emissions with a time lag is a challenge, but it is a more appropriate approach for the calculation of projections compared to e.g. mass balances, which would assume immediate emissions after deposition in a landfill.

The GHG model has been completed with CO_2, N_2O and CH_4 emissions from all sources (landfill, incineration, and recycling - including composting), and all emissions have been converted to CO_2-equivalents, so the figures can be compared. The so-called characterisation factors used for establishing these comparisons are presented in Table 5.1. These factors reflect the relative contribution of each substance to global warming compared to the effect that carbon dioxide has. The 100 years time horizon has been chosen.

Table 5.1 Global warming potentials used for characterisation of greenhouse gas emissions

Species	Chemical formula	Lifetime (years)	Global Warming Potential (time horizon)		
			20 years	**100 years**	500 years
Carbon dioxide	CO_2	variable	1	**1**	1
Methane	CH_4	12±3	56	**25**	6.5
Nitrous oxide	N_2O	120	280	**298**	170

Note: The GWP for methane includes indirect effects of tropospheric ozone production and stratospheric water vapour production.
Source: IPCC (2007)

5.2. IPCC guideline and country reports to UNFCCC

The emission of greenhouse gasses from the waste sector in Europe has been reported in EEA (2009), based on national inventories reported by the EU Member States, as part of the countries' commitment under the UNFCCC. As mentioned above the definition of the waste sector within the IPCC reporting excludes several waste management activities like recycling or energy recovery of waste.

In 1995, the Intergovernmental Panel on Climate Change published a set of guidelines on GHG emissions accounting. COP3 in Kyoto in 1997 confirmed that the so-called IPCC Guidelines should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases". The latest available version of the guideline is from 2006 (IPCC, 2006).

The IPCC Guidelines describe in detail how to model greenhouse gas emissions from waste management (composting, anaerobic digestion in biogas facilities, incineration without energy recovery, landfilling and waste water treatment), and are the point of departure for the reporting of countries to the UNFCCC. Some countries use the default method proposed in the IPCC guideline, and other countries have chosen to develop alternative, national specific, yet IPCC-compliant, modelling methods that national experts believe better match national waste generation and management characteristics.

Using either the IPCC proposed method or national methods, all EU Member States report yearly their estimates of greenhouse gas emissions from waste management to the UNFCCC and the European Commission in the form of the so-called National Inventory Reports (NIR) and a worksheet called Common Reporting Format (CRF).

The Member States' NIR and CRF is one of the main sources for the estimation of emissions from landfilling. The information contained is produced by national experts, it is homogeneous, internationally accepted, and in most cases well documented. The information contained takes 1990 as the reference year, i.e., it provides in the best cases information for the period 1990-2007.

The EEA reports (2005, 2006, 2007) include figures and tables giving an overview of the methodologies, and data completeness of the NIR and CRF from EU-27.

For the calculations included in this project, the main data sources are the NIR and CRF of the EU-27 Member States + Norway and Switzerland, and the data on municipal waste generation, landfilling and incineration reported by Eurostat.

The data contained in the waste section in the NIR and CRF consists of two parts:
1) Activity data: are data on amounts of landfilled biodegradable waste. These data may be based on measurements (of % of biodegradable material in landfilled waste, and of total weights landfilled), or be estimated from other data such as population, per capita generation, and waste management practices.

2) Emission factors: are based on parameters representing physicochemical processes in landfills and incinerators, and help to model greenhouse gas emissions from waste containing carbon and nitrogen. These parameters can be for instance biodegradation and oxidation rates, gas recovery conditions in landfills, combustion conditions, or flue gas cleaning equipment in incinerators.

Both parts are necessary for estimating the direct greenhouse gas emissions from landfill and incineration of waste. Although the IPCC defined waste sector only includes incineration without energy recovery, the methodological recommendations of the IPCC guidelines can be transferred to model *direct* emissions only from incineration with energy recovery. The energy recovery is modelled entirely separately, since the associated GHG emissions are calculated based on the amount of energy recovered which substitutes the production of primary energy.

The time-dependent methodology developed by IPCC has been used to model emissions in all EU-27 countries + Norway and Switzerland, using the background activity information provided, and regardless of the method used in these countries for NIR and CRF reporting.

To model the emissions from landfill, the IPCC Guidelines propose a series of coefficients, which are technical parameters that help the modelling of the generation of direct GHG from landfill sites and incineration plants. The IPCC coefficients are used as default values, but national data have been used instead if reported by Member States in the NIR. When the coefficients are not available, they are estimated based on IPCC default values.

5.2.1. Waste composition

Unless otherwise specified, data on the composition of waste is acquired from the NIR and CRF reports to UNFCCC. The NIR provides information on the composition of the landfilled waste. However, it is assumed in this report that the incinerated quantities have the same composition as well. This is a weakness of the model and it should be corrected if better composition data are found. The information provided in the NIR indicates that the composition of waste remains constant in most cases. Therefore, it is assumed in this report that the composition will remain constant for the projection period (2008-2020) as well. This means that in the model, the composition of municipal waste in each country remains constant throughout the period 1990-2020[6]. The composition varies from country to country and for those countries that explicitly report the composition variation in the years 1990-2005, we have included that.

It is important to notice that the figures reported in NIR and CRF consider municipal waste as a sum of household and household-like waste *and* industrial biodegradable waste (which is inconsistent with the definition used by OECD and Eurostat). Therefore, it has been necessary to check and in some cases correct these figures in order to remove the industrial biodegradable waste.

The data used for the corrections in municipal waste composition are:

- Composition of generated waste: OECD (2001)
- Recovery rates, Source collection rates (paper, glass, biodegradable waste): OECD (2001), European Commission's reporting on the Landfill Directive (1999/31/EC)
- Information gathered by other ETC/SCP projects, though national EPAs and Statistical Offices (ETC/SCP, 2009).

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[6] For some countries the waste composition changes over the period (i.e. Ireland, Netherlands and Denmark).

In addition, the waste materials reported in the NIR/CRF diverges slightly from the model used in this project. The fractions not included in the model are for instance ‘sanitary household waste’, ‘unspecified biodegradable waste’, and ‘nappies’. These fractions are essentially a mixture of known biodegradable materials: food, garden, wood, paper, or textiles. Therefore, we have chosen to keep the division into known biodegradable materials: food, garden, wood, paper, and textiles, rather than include it in unspecified fractions. The fractions reported not matching these known materials have been divided according to the following qualified estimations:

- sanitary household waste: 33% paper, 33% textile, 33% plastic
- unspecified biodegradable waste: 50% food waste, 50% inert waste
- nappies is assumed to be composed of 95% paper, 5% plastic

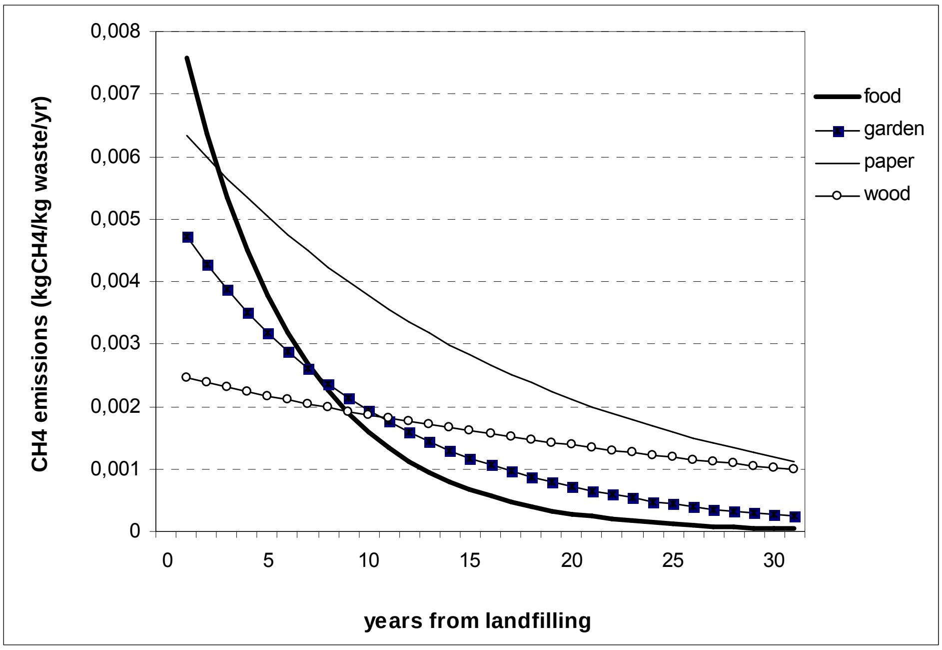
Furthermore, the values obtainable in the NIR/CRF are often aggregated values for total organic food and garden waste. Hence, we have calculated the amount of organic waste as food waste. Food waste and garden waste contain the same amount of degradable organic carbon, but have different half-life values. This implies that in the calculations, the speed at which the waste degrades is somewhat overrated. The total amount of methane generated is, however, the same.

5.3. Modelling GHG emissions from landfills

The 1996 and 2006 IPCC Guidelines distinguish two tiers for modelling landfill emissions. Tier 1 is a time-independent methane emission model where all emissions from a given waste are attributed to the year when waste was landfilled. Tier 2 allows to calculate the emissions and to display emission trends over time following a first order decay (FOD) model, and is more accurate to actual behaviour by not assigning all emissions to a single year. According to the IPCC Guideline, it is considered good practice to use a first order decay (FOD) model, that is, Tier 2.

Applying the Tier 2 method does not mean using exactly the equations and parameters proposed in the IPCC Guideline. Tier 2 indicates only that the estimation of the methane emissions from landfills must follow a first-order decay equation, which in plain words means that the amount of methane emitted is a function of the amount of biodegradable material remaining in the landfill at a given moment in time. This is expressed mathematically by a differential equation which, when integrated, results in an exponential, time dependent function, as illustrated in Figure 5.3 for 1kg of different waste materials with different degradation rates.

Figure 5.3 Example of methane emissions evolution over time using a first-order decay model



Note: The degradation of 1kg of different waste materials is presented, each material having a specific organic content and degradation rate (represented by the half-life degradation times, which in the example of this figure are food: 4 years, garden waste: 7 years, paper waste: 12 years, wood: 23 years).

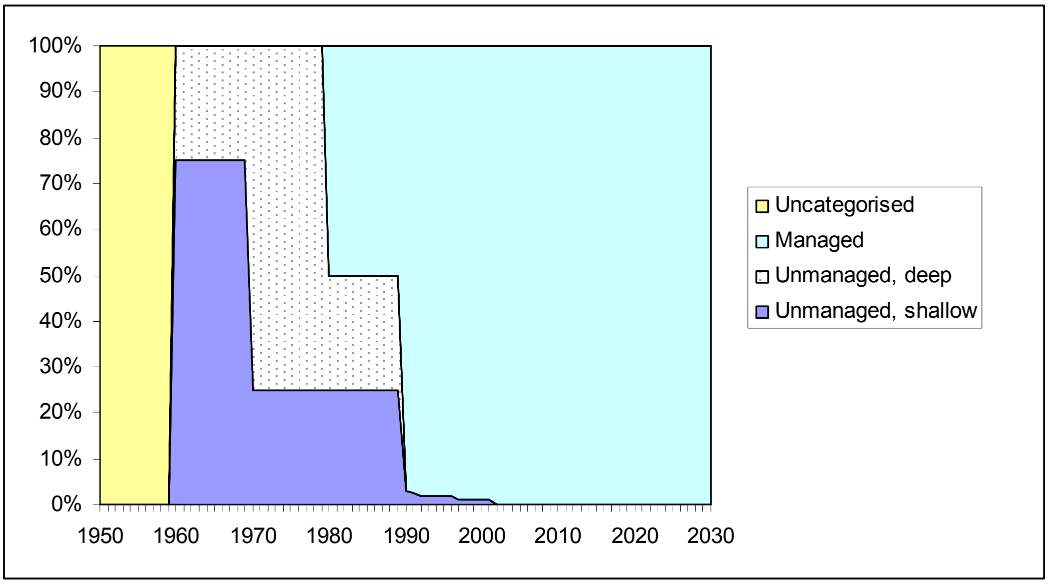
Countries apply various models and assumptions when reporting to the UNFCCC. The EEA (2007) reports that three Member States used a country-specific emission model in accordance with the Tier 2 method (Denmark, United Kingdom and Belgium) and four Member States (Sweden, Ireland, France and Finland) applied country-specific methods (or rather values) in accordance with the Tier 2 method. The remaining Member States applied the Tier 2 methodology (including default values) as proposed by the IPCC good practice guidance and the IPCC Guideline.

The modelling of landfill emissions has been undertaken using a two-string approach:
1) use of the NIR and CRF data exclusively
2) progressive refinement of data through contact to national experts where conflicts are observed. In many industrialised countries, waste management has undergone large changes during the last decade. Waste prevention and reuse policies have aimed at reducing the amount of waste generated. Increasingly, alternative waste management practices to waste disposal on land have been implemented to reduce the environmental impacts of waste management. Also landfill gas recovery has become more common as a measure to reduce methane emissions from solid waste disposal sites.

Regarding the time period in question, the landfilling modelling presents itself with some challenges. The time delay between the actual landfilling of waste and the emission of methane calls for a different approach than for other parts of the model. Therefore, a time series that dates back to 1950 is constructed. The composition of landfilled waste is assumed to remain constant. The emissions are, subsequently, modelled for the period 1950-2020, but only results for 1990-2020 are presented. In this way, the effects of landfilled waste during 1950-1990 are taken into account in the emissions during 1990-2020.

In the model, the methane correction factor (MCF) is used to take into account the fact that different types of landfills have different potentials for creating anaerobic conditions and subsequently develop methane. In the NIR/CRF reports, however, only data for the years 1990-2008 are available. While the landfill types applied in the years ahead can be assumed to consist manly of managed landfills, the landfill types in the past are more diverse. Hence, MCF values had to be estimated in the time span 1950-1990. In general, it has been assumed that prior to the use of managed landfills, landfilling was performed at a mix of shallow and deep unmanaged landfills. Furthermore, it has been assumed that when going back in time the share of shallow, unmanaged landfills will increase. This trend is incorporated in the assumed composition of landfill types in the period from 1950-1990. In the model, the MCF factors/landfill types change gradually every 10 years. Figure 5.4 illustrates the assumed evolution of landfill types (and MCF values) in Finland as an example.

Figure 5.4 Assumed evolution of landfill types (and MCF values) in Finland



5.3.1. Methane recovery rates

The maximum feasible recovery rate for methane gas is assumed to be 50%. This percentage is considered a maximum technically achievable recovery rate, and it has been used as the maximum, regardless of the values reported in the NIR and CRF. The countries in their reporting claim that higher methane extraction rates are attainable. According to the experience of Oonk (2006) and Willumsen (2005), the maximum recovery values in European landfills lie rather between 20% for landfills in operation and 37% for closed, controlled landfills. The IPCC Guideline estimates a default value of 20% (IPCC, 2006). According to the Guideline, country-specific values may be used, but then significant research is necessary to obtain information on the following parameters: cover type, percentage of solid waste disposal sites covered by recovery project, presence of a liner, open or closed status, and other factors.

This background analysis indicates and justifies the differences observed in countries' reporting to the UNFCCC, particularly the reported methane extraction rates. The highest value was reported by the UK (73% in 2007). ETC/SCP has contacted Golder Associates, which was responsible for compiling the UK NIR for 2005. According to them, a group of scientists from the UK were consulted in parallel to the landfill owners reporting. The result is depicted in the assumptions stated in the relevant report.

The IPCC proposed default value of 20% is considered to be outdated and overly conservative (also according to the IPCC 2006 guidelines). Moreover, ETC/SCP has consulted qualified experts and a general consensus was reached. 40-50% is considered to be a relatively conservative value for the maximum attainable methane extraction rate in the **lifetime** of waste landfilled. Therefore, the model adopts the countries' reported recovery figures, but they are capped at a maximum recovery rate of 50%.

More analytically, the countries' individual reporting to UNFCCC contains information about the national methane emissions from landfills and the amount that was recovered. From those figures, the recovery rate for each year is calculated. The latest historical data on methane recovery rates can be found in the 2009 NIRs, which were submitted to the UN by the countries in April 2009. They contain data for the greenhouse gas inventory of 2007. An adjustment of the reported figures is performed for each individual country, according to the following rules:

- For the countries that reach a rate above 40% already in the historical data time period (NIRs), a default value of 40% is used for 2007 (latest reported data). The value for 1990 remains unchanged, but the years from 1991 to 2006 are completed by using the growth rate calculated from the reported methane recovery rates. From 2008 to 2020 the recovery rate will be linearly increased to 50% (e.g. BE, UK) in order to account for technological developments.
- For the countries that do not reach a rate over 40% within the historical data (1991-2008), an average of the increase rate of the methane extraction is drawn for the last five years of historical data. This rate is applied to each year from 2008 until 2020. The first value that exceeds 40% is set to 40% and from then on, a linear increase follows so that the rate is 50% in 2020 (e.g. FI). If no value exceeds 40% until 2020 no intervention is necessary.
- In countries where a rate of 0% has been reported until 2007, we have assumed that the recovery of methane starts in 2013 by 2%. This is an anticipated result of the Landfill Directive (1999/31/EC). Furthermore, we have assumed that these countries reach a recovery rate of 20% in 2020.

At this point, the implications of the implementation of the Landfill Directive for the future methane recovery rate should be underlined: The fact that smaller biodegradable MSW quantities will be landfilled limits the absolute methane emissions. Moreover, the lower percentage of biodegradable MSW landfilled would affect the methanogenic processes within the landfill cells. Therefore, the economic feasibility of installing high tech capture equipment is challenged.

5.4. Modelling GHG emissions from incineration

The estimations of emissions from incineration are based on the composition of the waste and the mass balance of carbon. The calculation is as follows:

$$\textit{kg CO2/year} = \textit{kg MSW for incineration} \cdot \textit{oxidation factor of carbon in incinerator (0,98)} \cdot \textit{conversion factor of C to } CO_2 \textit{ (3.67)} \cdot \sum(\textit{waste fraction}_i \textit{ (in \%)} \cdot \textit{dry matter content}_i \cdot \textit{carbon content}_i \textit{ (g/g dry weight)})$$

The emission factors used are presented in Table 5.2.

Table 5.2 Emission factors used for incineration processes

	Food	Garden	Paper	Wood	Textile	Plastics	Inert
Dry matter content of the materials in waste	0.4	0.35	0.9	0.85	0.8	1	0.9
Carbon content of the materials (Gg C/Gg dry weight waste)	0.38	0.49	0.46	0.5	0.5	0.75	0

Source: IPCC Guidelines, 2006

5.5. Modelling GHG emissions from recycling

Recycling of municipal waste is a complex mix of several treatment processes. In 2006, the ETC/RWM carried out a study (ETC/RWM, 2006) that included collection of data and modelling of the environmental impacts from the recycling processes of organic waste, paper, plastic, glass, metals and wood. Based on this data, complemented with data on textiles extracted from the Gabi EDIP database[7], we have modelled the total emissions from recycling of municipal waste, except for food and garden waste.

Food and garden waste recycling is distributed into specific "recycling" options, i.e. composting, home composting and anaerobic digestion. Emission factors are used for the modelling of the GHG emissions emitted by each of the alternatives. The factors for central composting and anaerobic digestion are taken from the database of Institut für Energie und Umweltforschung (IFEU), while the values for home composting are extracted from (Boldrin, 2010) and refer mainly to garden waste.

Table 5.3 shows how the recycling processes are modelled and the data sources used. With regard to the incineration of waste, a 50/50 distribution on medium and high standard incineration plants is used to calculate the output of electricity and thermal energy.

Table 5.3 Waste treatment processes

	Recycling	Incineration[8]	Landfill	Data sources
Food and garden waste	Home composting, central composting and anaerobic digestion, shares individual per country.	Incineration plant, 50% medium standard, 50% high standard	Methane for recovery	ETC/RWM, 2006 IFEU Database Boldrin, 2010
Paper and cardboard	Material recycling, 50% pulping + deinking (newspaper & copypaper), 50% pulper (cardboard)	Incineration plant, 50% medium standard, 50% high standard	Methane for recovery	ETC/RWM, 2006
Plastic	Material recycling, gasification, incineration of residuals	Incineration plant, 50% medium standard, 50% high standard	No degradation	ETC/RWM, 2006
Glass	Production of glass cullets	No incineration	No degradation	ETC/RWM, 2006
Metals	Material recycling, 33% aluminium, 67% tinplate	No incineration	No degradation	ETC/RWM, 2006
Wood	Production of wood chips	Biomass heating power plant high standard	Methane for recovery	ETC/RWM, 2006
Textile	Material recycling, 40% cotton, 60% polyester	Incineration plant	Methane for recovery	Gabi EDIP database

The resulting emission factors are shown in Table 5.4 and 5.5 for food and garden waste. These are based on 2006 data and we have assumed that this will not change during time. Of course, the processes have been less efficient in previous times and are expected to

[7] EDIP is the official Danish LCA database maintained by LCA Center Denmark, www.lca-center.dk

[8] High and medium standards refer to the efficiency of flue gas cleaning. Efficiency: net electricity = 10%; net thermal energy = 30%. For wood, high standard means that the plant meets the requirements of the German directive on combustion (17. BImSchV) and therefore wood containing hazardous substances is allowed to be treated in this plant. Efficiency: net electricity = 19%; net thermal energy = 46%.

become more efficient in future times. However, we have not had access to information to justify such type of projections.

Table 5.4 Emission factors used for recycling processes

	Paper & cardboard	Plastic	Glass	Metals	Wood	Textile
gCO_2/g material	1.1E-01	1.3E+00	2.1E-02	8.6E-01	2.4E-02	2.2E-01
gCH_4/g material	2.17E-04	6.02E-04	1.00E-05	1.09E-03	4.10E-05	4.29E-04
gN_2O/g material	3.06E-06	7.04E-07	1.92E-08	1.01E-05	1.10E-05	5.56E-06

Table 5.5 Emission factors used for recycling of food and garden waste

	Food & garden waste		
	Composting	Home composting	Anaerobic digestion
gCO_2/g material	1.09E-01	0	1.38E-01

Most of the processes represent German facilities, since no European averages exist in the LCA databases. In order to account for the variations in the mix of energy sources in Europe, the German energy mix has been substituted by a country specific electricity mix, but this has a very low influence on the direct emissions from recycling. The emissions from this energy mix is calculated using LCA data sets on electricity and heat production from the European Reference Life Cycle Data System (ELCD) and information on the consumption of electricity and heat in the European countries from the International Energy Agency. Ireland, Cyprus and Malta have not been included due to lack of data.

The estimated emissions per MJ energy produced are shown in Table 5.6. These were converted into CO_2-equivalents using the conversion factors presented in Table 5.1.

Table 5.6 Estimated emissions from the production of electricity and thermal energy, EU-25, kg/MJ

	Electricity	Thermal energy
CO_2	0.16	0.067
N_2O	3.9E-06	1.9E-06
CH_4	0.0003	0.0002

Sources: Electricity: European LCA platform ELCD data on electricity production in the EU countries (2002) + IEA energy consumption statistics (2004); Thermal energy: European LCA platform ELCD data on thermal energy production in EU-25 (2002)

5.6. Estimation of avoided emissions

The model also takes into account waste management benefits resulting from the production of energy from the incineration of waste and combustion of landfill gas and from the recycling of secondary materials. Such benefits are characterized by avoided emissions from the production of energy from fossil fuels and from manufacturing based on virgin materials.

This part of the model is based on life cycle data collected from ETC/RWM (2006) and the Gabi EDIP database. The data for food and garden waste are collected from IFEU and Boldrin (2009). As it is the case with the direct effects from recycling, the German energy mix used previously for the modelling (ETC/RWM, 2008; EEA, 2008) has been replaced by country specific energy mixes for the purpose of calculating the avoided emissions from recycling . Moreover, the saved energy production from methane recovery and waste incineration is calculated on the basis of national energy mixes. Hence, we assume that the emissions saved by energy production equal the average emissions from energy production in each specific country. The average emissions were found in the ELCD database.

The selected country-specific energy mix is assumed to remain constant throughout the entire time period of the modelling (1990-2020). This assumption has an important effect on the overall results and a further investigation should be made in order to assess the development of energy mixes over time. Moreover, this assumption contradicts to some extent the efforts put into increasing the renewable part of the energy mix by some MS or the EU. However, a detailed analysis of the energy mix is outside the scope of this study, but a sensitivity analysis of the effect of an energy mix with lower average GHG emissions on the overall results of the modelling has been carried out and is described in section 7.1.3.

Table 5.7 presents the processes that we have used to model the emissions avoided by landfilling, incineration and recycling. For landfilling, only the biodegradable waste fractions contribute to the energy recovery. In the incineration plant, there are no benefits from glass and metals[9]. By recycling, the use of virgin materials is avoided, and thus the emissions from production of these materials are saved.

Table 5.7 Production processes avoided by recycling, incineration and landfilling

	Saved energy production from methane recovery	Saved energy production from incineration	Saved material/energy production by recycling
Organic waste	Electricity	Electricity and thermal energy	Organic substance, mineral fertilizer, electricity and thermal energy[10]
Paper and cardboard	Electricity	Electricity and thermal energy	Newspaper, copy paper, cardboard
Plastic	No benefits	Electricity and thermal energy	Polyolefins, polyethylen, polystyrene, wood and concrete palisades, methanol
Glass	No benefits	No benefits	Glass bottles (with 71% cullets)
Metals	No benefits	No benefits	Aluminium and tinplate
Wood	Electricity	Electricity and thermal energy	Industrial wood (harvesting and processing for use as chipboards)
Textile	Electricity	Electricity and thermal energy	Cotton fibres and polyester

5.6.1. Landfills

The avoided emissions from landfilling have been calculated by converting the amount of methane recovered into the potential amount of energy produced from this recovery. A maximum of 50% recovery of landfill gas is used for all of the waste fractions (see also chapter 5.3). We used a higher heating value (HHV)[11] of methane of 55 MJ/kg CH_4.

Table 5.8 Estimated amount of methane available for recovery from each waste fraction (kg CH4/kg wet material)

Food	Garden	Paper	Wood	Textile	Plastics	Metals	Inert
0.011	0.012	0.029	0.032	0.018	0	0	0

Estimation based on IPCC Guidelines, 2006

[9] The metals that are collected from the bottom ash are accounted for in the recycling scheme.

[10] Depending on the chosen treatment option.

[11] HHV is the amount of energy released when waste is combusted, without taking into account the enthalpy of the water content.

For methane recovery, we assume that only electricity is produced and that this is done with an efficiency of 33% (CIWM, 2003). As already mentioned, the average emissions from the national electricity mix in each country is applied.

On this basis, we have calculated the avoided emissions from landfills as:

$$CO_2 \textit{ savings} = \textit{methane for recovery (kg)} \cdot \textit{HHV (MJ/kg)} \cdot \textit{efficiency (33\%)} \cdot CO_2 \textit{ emissions/MJ for electricity}$$

where the CO_2 emissions per MJ represents the average emissions of the energy mix in each country.

5.6.2. Incineration

To estimate the avoided emissions from incineration, we have calculated how much energy is produced in the incineration plants. The potential for energy production was calculated as follows:

$$\textit{Energy content} = \textit{kg waste incinerated} \cdot \sum(\textit{waste fraction}_i \textit{ (\%)} \cdot \textit{calorific value}_i \textit{ (J/kg)})$$

The calorific values of the different waste fractions are shown in Table 5.9.

Table 5.9 Calorific value of waste fractions

	Food	Garden	Paper	Wood	Textile	Plastics	Inert
Calorific value of the materials (GJ/Mg)	2	5	15	15	16	30	0

Source: IPCC Guidelines, 2006

The distribution of energy on electricity and heat in the incineration plants is estimated on the basis of CIWM (2003) and CEWEP[12] national reports. The avoided emissions from incineration have been calculated as follows:

$$CO_2 \textit{ savings} = \textit{energy content (MJ)} \cdot (\textit{electricity\%} \cdot \textit{efficiency} \cdot CO_2 \textit{ emissions/MJ for electricity} + \textit{heat\%} \cdot \textit{efficiency} \cdot CO_2 \textit{ emissions/MJ for thermal energy})$$

where the CO_2 emissions per MJ electricity represents the average emissions of the energy mix **in each country**, and the CO_2 emissions per MJ thermal energy represents **EU-25 mix** as shown in Table 5.6 above. It is not possible to customise the thermal energy mix data per country as in the electricity case because of data unavailability. So the overall mix for EU-25 is used instead.

5.6.3. Recycling

The calculation of the avoided emissions from recycling was based on life cycle information in the same way as the direct effects were modelled, only the emission factors were changed. Emission factors for avoided emissions were derived from the EDIP Database, 2006 (table 5.10).

5.6.4. Total avoided emissions

The total sum of CO_2-equivalents for each of the treatment methods is shown in Table 5.10. There are some uncertainties linked to these figures as they are mainly based on German data and to some extent on EU-25 energy averages.

Table 5.10 Emission factors used for estimation of avoided emissions

gCO_2-equivalents/ g material	Organic waste	Paper & cardboard	Plastic	Glass	Metals	Wood	Textile

[12] Confederation of European Waste-to-Energy plants.

Landfilling	-0.06	-0.15	0.00	0.00	0.00	-0.17	-0.09
Incineration	-0.09	-0.70	-1.29	0.00	0.00	-0.96	-2.31
Recycling	-0.08 (C) -0.09 (HC) -0.18 (AD)[13]	-0.68	-1.72	-0.18	-4.11	-0.09	-1.96

Source: EDIP Database, 2006

In this project we were not concerned with the relative differences between the treatment options, but only the absolute values of the direct and the avoided emissions. To gain more information on comparisons of waste treatment we refer to two studies: a Topic Centre's previous study that compares environmental impacts from the treatment of paper (EEA, 2006) and another about other waste fractions (WRAP, 2006) on the basis of several life cycle assessments. The emission factors are kept constant over the full time period as no reliable information about development in emission factors is available.

5.7. Biogenic and anthropogenic CO_2 emissions

In the model, GHG emissions have been split into two categories: anthropogenic and biogenic, following the IPCC definitions (IPCC, 2006). The results presented in this report include only the anthropogenic CO_2 emissions. We have assumed that the CO_2 released from the incineration of plastics and the fraction of synthetic textiles (60%) is anthropogenic. For landfilling, we have considered plastics, glass and metals as well as 40% of the textiles as inert materials, and the CO_2 emissions from the remaining fractions are all biogenic. However, considerable CH_4 emissions are released from landfills, and these are accounted for as anthropogenic. We assume that all N_2O emissions are anthropogenic.

5.8. Waste collection – transport

We have used the data on collection of waste that was also modelled in ETC/RWM (2006). Table 5.11 shows the distances and the emissions in CO_2-equivalents.

Table 5.11 Transport distances and emissions

Waste fraction		**Vehicle and distances**	**g CO_2-eqivalents/ kg material**
MSW for incineration and landfilling		Refuse collection vehicle; collection tour: 11.46 km; distance to sorting plant: 14.52 km (medium data for Germany)	7.59
Recycling	Organic waste	Refuse collection vehicle; collection tour: 14,425 km; distance to sorting plant: 16,85 km (medium data for Germany)	9.83
	Paper & cardboard	Refuse collection vehicle; collection tour: 14,25 km; distance to sorting plant: 13,93 km (medium data for Germany)	10.07
	Plastic Wood Textile	Refuse collection vehicle; collection tour: 11,32 km; distance to sorting plant: 15,44 km (medium data for Germany)	17.36
	Glass	Refuse collection vehicle; collection tour: 15 km; distance to sorting plant: 75 km (medium data for Germany)	15.11
	Wood	Refuse collection vehicle; collection tour: 10,9 km; distance to sorting plant: 14,8 km (medium data for Germany)	11.94

Source : ETC/RWM (2006)

The fact that the transport distances are drawn from German data leaves some room for uncertainty. Other modelled countries might have higher or lower distances compared to Germany, but the uncertainty of this assumption does not significantly affect the overall results since, in terms of GHG emissions from waste management, transport does not contribute significantly (see results in chapter 6).

[13] C stands for central composting, HC for home composting and AD for anaerobic digestion.

6. Baseline scenario for municipal waste generation

In this section we present a likely future development in the generation of waste, management of waste and emission of greenhouse gases based on the model and assumptions described in sections 3 to 5. The baseline scenario assumes that no new and innovative policy measures are introduced to further prevent the generation of waste or to further divert waste from landfill.

The baseline scenario has been designed to assume what is likely to happen – not necessarily to meet the objectives of the Sixth Environment Action Programme or targets of specific directives, such as the Landfill Directive.

6.1. Municipal waste generation

Chapter 3 described how future MSW generation is estimated through a model that takes into account the econometric parameters' influence on waste production.

The resulting projected growth in the municipal waste generation in the EU Member States, Norway and Switzerland is presented in Tables 6.1 and 6.2.

In the EU-15+Norway and Switzerland, the generation of municipal waste is projected to decrease by 2.13% from 2008 to 2010 and to increase by 6.29% in 2020. In the EU-12 waste generation is projected to grow faster than in the EU-15 + Norway and Switzerland, but it is more susceptible to the economic crisis, i.e. a decrease of 3.65% in the crisis years 2008-2010 and an increase by 9.33% from 2008 to 2020[14].

Table 6.1 Projected growth in municipal waste generation in the EU-15 + Norway and Switzerland, 2008-2020

	%	AT	BE	DE	DK	ES	FI	FR	GR	IE
Generation increase	2008-10	10.7%	-1.2%	-8.7%	-10.3%	-4.5%	-6.3%	-5.9%	0.7%	4.1%
	2008-20	16.3%	6.0%	-2.7%	-3.2%	-3.9%	2.9%	-5.1%	16.5%	20.0%
	%	IT	LU	NL	PT	SE	UK	CH	NO	EU-15+CH, NO
	2008-10	-0.1%	2.0%	0.7%	-5.8%	-12.3%	4.4%	17.6%	44.3%	-2.1%
	2008-20	9.3%	19.1%	12.5%	8.1%	-2.6%	23.9%	23.6%	75.0%	6.3%

Table 6.2 Projected growth in municipal waste generation in the EU-12 , 2005-2020

	%	CZ	EE	HU	LT	LV	MT
Generation increase	2008-10	-0.5%	-17.1%	2.8%	-12.9%	-1.2%	4.3%
	2008-20	12.4%	-8.6%	7.9%	-5.1%	41.2%	22.6%
	%	PL	SI	SK	BG	RO	EU-12
	2008-10	-13.6%	-13.2%	-0.2%	1.1%	6.4%	-3.7%
	2008-20	-3.6%	11.0%	25.2%	15.6%	21.5%	9.3%

The generation of municipal waste in the EU-15 + Norway and Switzerland from 2005 to 2020 is presented in Figure 6.1. From the figure it becomes evident that the five most populated countries produce the majority of waste in the EU-15 + Norway and Switzer-

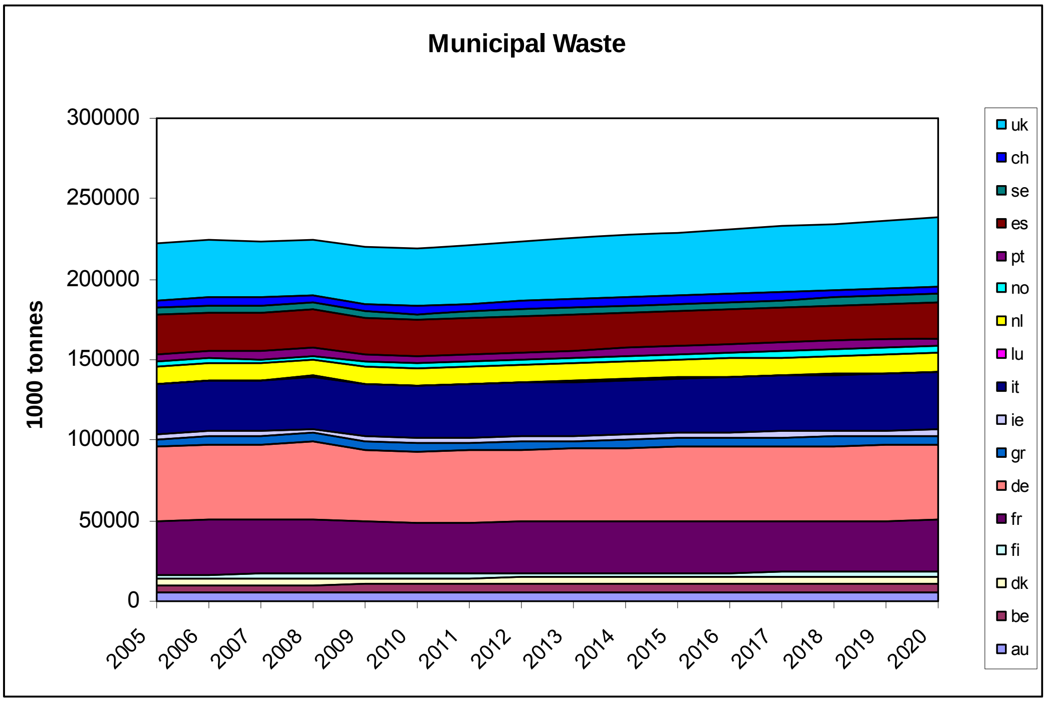
[14] In some cases (e.g. DK) the negative growth for 2008-2010 can be reversed into positive growth for 2008-2020. The reason is that the projections model takes into account a long historical data time series, not only the latest registered trends. Please also see chapter 3.1

land. In fact, about 80% of the waste is generated in Germany, the United Kingdom, France, Italy and Spain together.

As seen from Figure 6.2, a similar situation applies for the EU-12 where Poland, Romania and Hungary produce around 70% of the municipal waste generated.

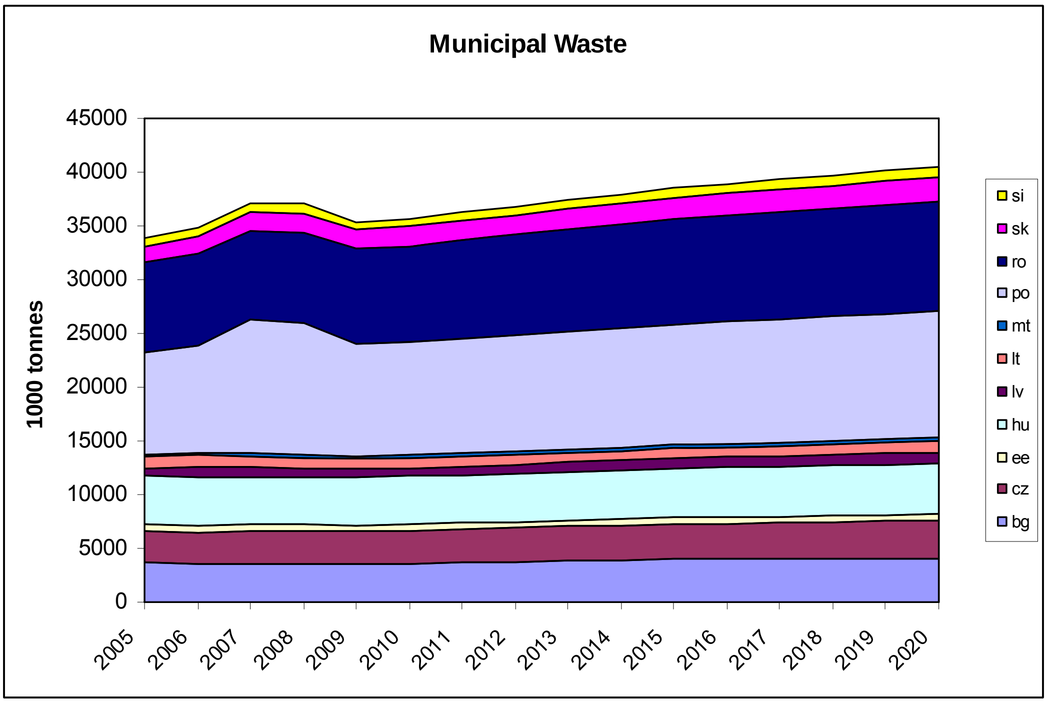
In all diagrams, the consequences of the economic crisis (2008-2010) are depicted as a decrease of waste generation during the same period.

Figure 6.1 Generation of municipal waste in the EU-15 + Norway and Switzerland, 2005-2020



Note: Country codes, see Annex I.

Figure 6.2 Generation of municipal waste in the EU-12, 2005-2020



Note: Country codes, see Annex I.

Since it is assumed that the decoupling of municipal waste generation from economic growth will not be achieved at the EU level before 2020, the developments in the economic figures greatly affect the waste arisings. In 2010 the generation of municipal waste in the EU-27+Norway and Switzerland is projected to be around 255 million tonnes with a further increase to approximately 279 million tonnes in 2020. The projected amounts for each country are shown in Tables 6.3 and 6.4.

Table 6.3 Projected generation of municipal waste in the EU-15 + Norway and Switzerland, million tonnes, 2010 and 2020

	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	CH	NO	EU-15+ CH,NO
2010	5.4	5.1	44.0	3.9	22.4	2.6	31.8	5.0	3.1	32.5	0.3	10.4	4.6	4.0	35.9	5.0	3.3	219.4
2020	5.7	5.4	46.9	4.2	22.5	2.8	32.1	5.8	3.6	35.5	0.4	11.6	5.3	4.5	42.6	5.3	4.0	238.3

Table 6.4 Projected generation of municipal waste in the EU-12, 2010 and 2020

	CZ	EE	HU	LT	LV	MT	PL	SI	SK	BG	RO	EU-12
2010	3.1	0.5	4.5	0.9	0.7	0.3	10.6	0.8	1.8	3.6	8.9	35.7
2020	3.5	0.6	4.7	1.0	1.1	0.3	11.8	1.0	2.2	4.1	10.2	40.5

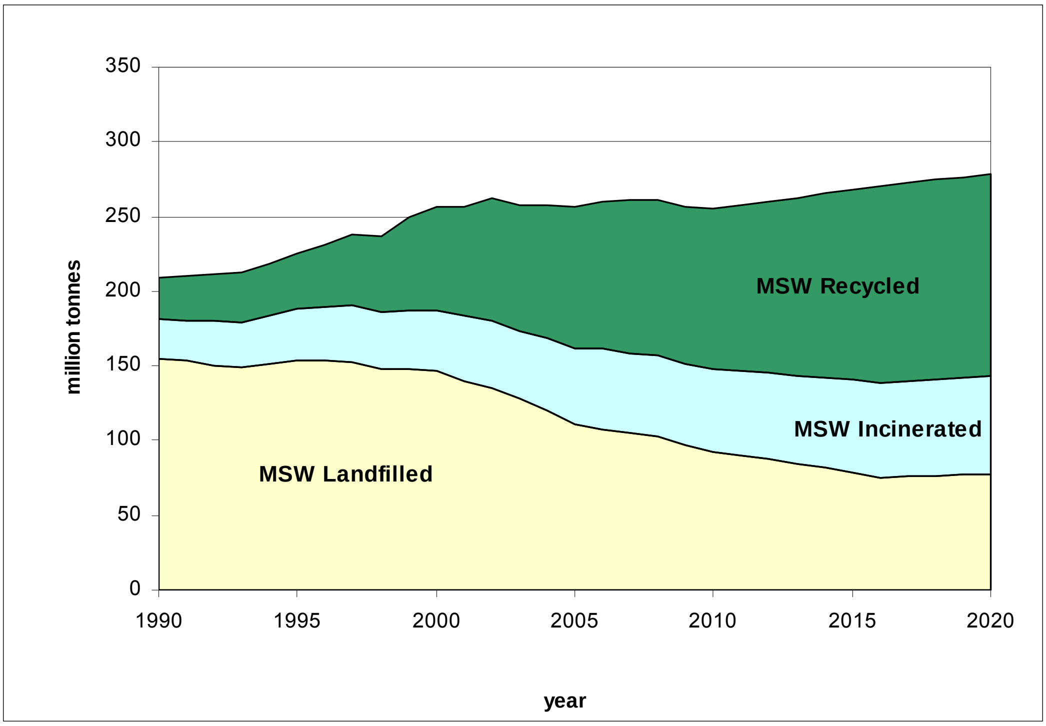
6.2. Municipal waste management

The projected management of waste in the EU-27 + Norway and Switzerland is illustrated in Figure 6.3. In 1990, more than 70% of municipal waste was disposed of in landfills. However, in the beginning of the 1990s, several countries began introducing policies to reduce the use of landfills as outlets for municipal waste. In 1994 and 1999, two directives aiming to increase the recycling and recovery of packaging waste (Packaging and Packaging Waste Directive) and to divert biodegradable municipal waste away from landfill (Landfill Directive) were introduced. The target of increasing material recovery is also served by the revised Waste Framework Directive, which sets specific recycling targets for the main municipal waste fractions. All these directives have reinforced the diversion of waste from landfill.

It is expected that the diversion will continue, but a slight increase in the total amounts of landfilled waste is seen from 2017 while the share of landfill in waste management remains almost constant (slight decreases). The model uses relative shares of landfill, incineration and recycling and, due to the considerable increase in waste generation, the landfill share will have to be very low if the absolute amount of landfilled waste is to remain at a constant level or even decrease. In 2020, 28% of the generated waste is assumed to be landfilled. Incineration of waste with energy recovery is assumed to reach 23% in 2020. The development of the shares of landfilling and incineration are shown in annex III.

The effect of the economic downturn on waste generation is important, since the waste arisings fluctuate according to the economic developments. Some policies might be triggered or differentiated, if more (or less) waste quantities arise, which may affect the waste distribution into treatment options. Moreover, some countries might cancel or postpone investments in waste management. However, the binding character of current legislation would still incentivise countries to improve MSW management so the effect of legislation is reflected in the assumptions for the forecast presented in figure 6.3.

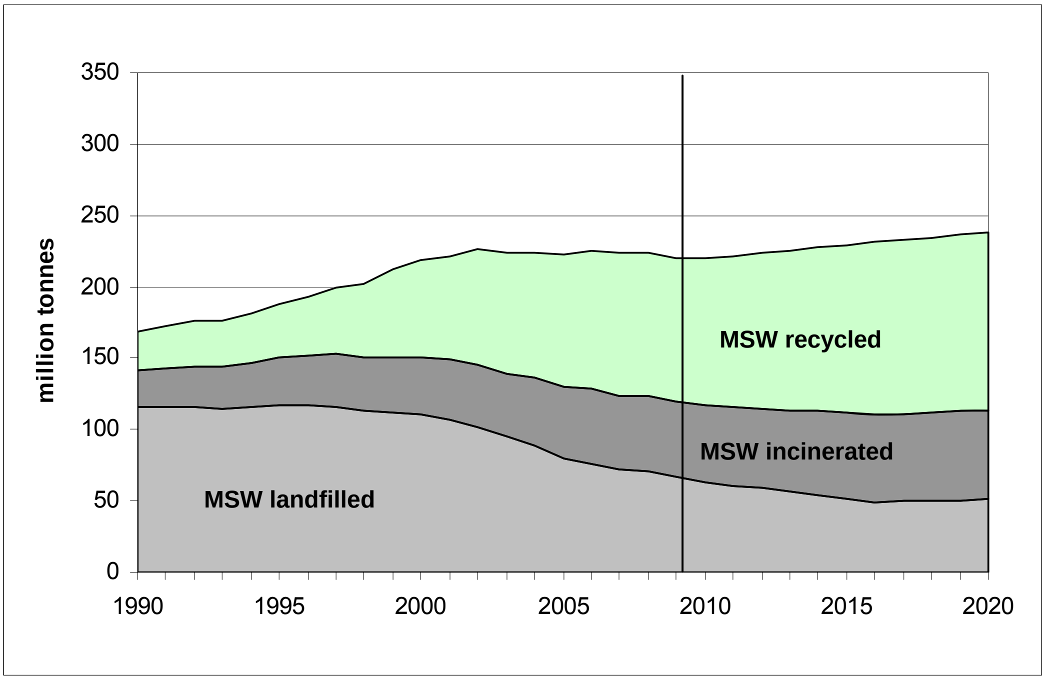
Figure 6.3 Municipal waste management in the EU-27 + Norway and Switzerland



Figures 6.4 and 6.5 show the management of municipal waste in the EU-15 + Norway and Switzerland and the EU-12 respectively.

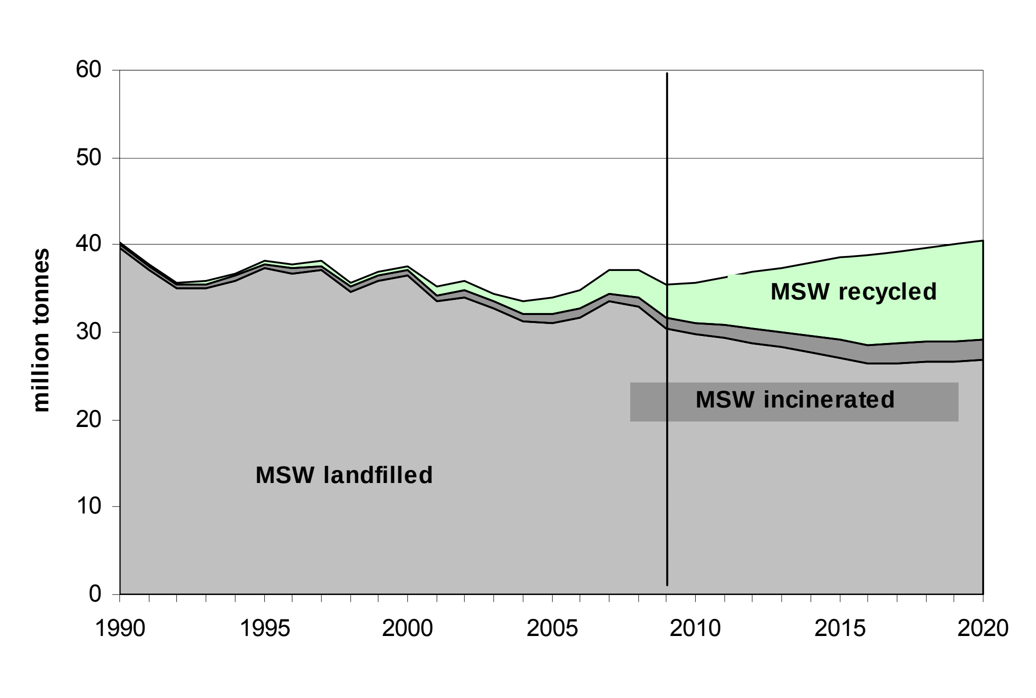
Most municipal waste was landfilled in the EU-15 + Norway and Switzerland in 1990. From the 1990s Member States started to expand their recycling activities noticeably and the EU Packaging and Packaging Waste Directive was issued in 1994. This trend is expected to continue, albeit at a slower rate. Incineration with energy recovery is also expected to increase to some extent.

Figure 6.4 Municipal waste management in the EU-15+ Norway and Switzerland



Note: the line in 2009 shows when the projection begins.

Figure 6.5 Municipal waste management in the EU-12



Note: the line in 2009 shows when the projection begins.

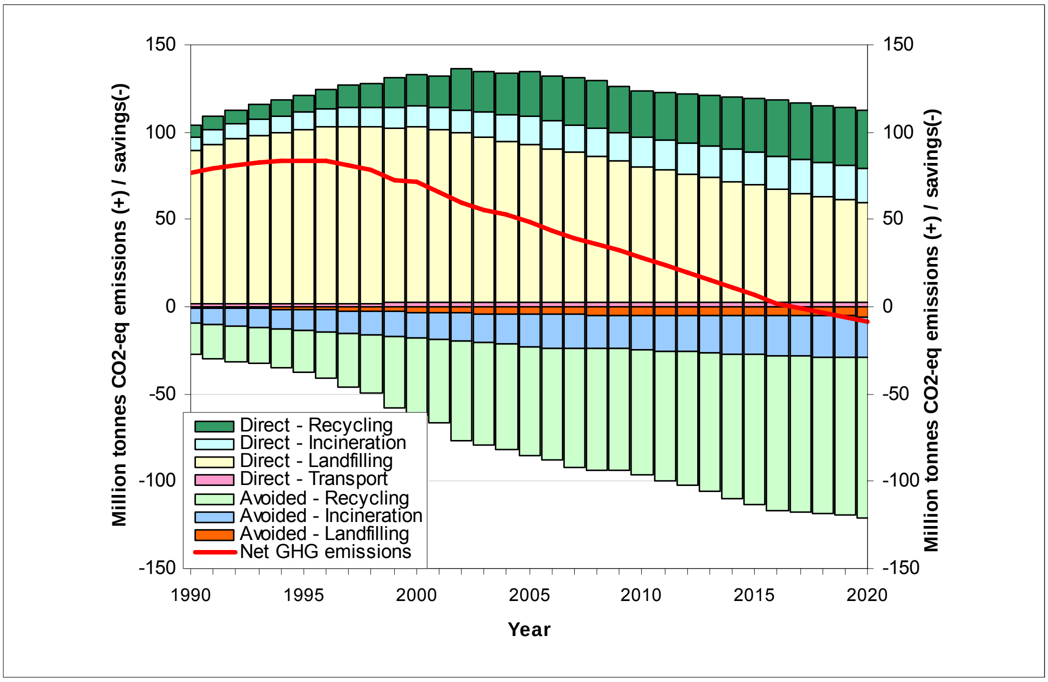
In the EU-12 almost all waste was landfilled in 1990. This situation continued after 1990, but some countries such as Slovenia and Hungary started to divert waste from landfills. Most countries started or intensified the diversion after 2000. For example, the Czech Republic and Estonia both have decreasing landfill rates from 2001. Some countries have had limited or no success in the reduction of landfilled quantities such as Bulgaria and Romania.

In the baseline scenario, the landfill of municipal waste will decrease to around 66% in 2020. Very little waste was incinerated with energy recovery before 2005, but we have assumed that this will increase to around 6% in 2020.

7. Greenhouse gas emissions

In order to obtain an overall view of waste management, the net balance of greenhouse gas emissions is calculated. Figure 7.1 presents the direct emissions from landfill sites, incineration plants, recycling operations and collection of waste on the positive side of the y-axis.

Figure 7.1 Net greenhouse gas emissions from municipal waste in EU-27 + Norway and Switzerland (million tonnes CO_2-equivalents)



Direct emissions represent, however, only a part of the picture of GHG emissions from waste. The energy and secondary materials produced when incinerating and recycling waste replace energy production from fossil fuels and the use of virgin materials for plastics, paper, metals etc. Using life-cycle information, these 'savings' or avoided emissions can be translated into CO_2-equivalents, as presented on the negative side of the y-axis. The mentioned savings also include a minor contribution from landfills, namely the avoided CO_2 emissions when methane is recovered in landfills and used as an energy source, substituting traditional (mostly fossil-fuel based) energy production.

Moreover, if a country has a very low landfill rate as a consequence of high recycling and possibly energy recovery (combined with a low growth in waste volumes), the net emissions of greenhouse gases from the waste management system may even become negative. This means that an effective management of waste with high recycling and possibly incineration can partly offset the emissions that occurred when the raw materials and products were extracted and manufactured.

The reduction in the net GHG emissions is a consequence of two factors: the decrease in the direct emissions and the increase in the avoided emissions. The sum of the direct emissions and avoided emissions from each treatment option can be seen in figure 7.1. After around the year 1995, the direct emissions start to reduce. This is not caused by less waste generated, but by more efficient operation of the waste management system as a whole. This means, that even if the waste generation is increasing, the redistribution of waste into different treatment options (improved waste management) can lead to reductions in GHG emissions. Starting in 1995, but more consistently after 2000, there is a clear shift from landfilling to recycling. Therefore, the direct emissions from landfilling start to decrease while the direct emissions from recycling increase. However, MSW landfilled has much higher direct emissions than when recycled, hence the reduction in the overall direct emissions.

The shift from landfilling to recycling has an even larger positive effect on avoided emissions. The energy recovered from landfills avoids emissions from production of primary energy, while the material recovery avoids emissions from production of primary materials. However, the benefit from the energy recovery of methane from landfills is much smaller than the corresponding benefit from material recovery. Therefore it is the shift towards recycling that contributes most to the increase in avoided emissions.

The combination of these two factors (direct and avoided emissions) leads to an overall decrease in the net GHG emissions of the European MSW management system that begins around the year 1995 and continues over time.

The estimated emissions of greenhouse gases in the EU-27 + Norway and Switzerland for the period 1990 to 2020 are shown in Figure 7.1. The net emissions of greenhouse gases from the management of municipal waste are projected to decline from around 76 million tonnes CO_2-equivalents per year in 1990 to -8 million tonnes CO_2-equivalents by 2020. This corresponds to a net reduction of 84 million tonnes CO_2-equivalents . This decrease over time of GHG emissions implies that the waste management system contributes to or facilitates compliance with the Kyoto targets for the EU-15 countries and emission reduction targets for the EU-27.

According to this model, one could come to the conclusion that the more waste is generated and managed well, the better. This is of course not the case. The reason is that the model used here is focusing on the waste management of products only, i.e. “from gate to grave”. The environmental burden of materials and products before they become waste, namely the extraction of raw materials, production and use phases, are not accounted for. Therefore, if municipal waste management is provoking more benefits than burdens, the emissions from the previous phases are *only partly* offset. The results of this report do not give any insight into the life cycle impacts of the materials under study.

Waste prevention addresses the full life cycle of a product. If the net emissions for the management of one tonne of waste are negative (after around 2010 in figure 7.1), waste prevention, namely less waste, would deteriorate the benefits caused by better MSW management. On the other hand, it would reduce also the emissions from the previous phases of the life cycle, where the net GHG emissions are positive and higher than any avoided emissions achieved in the disposal phase. Therefore, waste prevention aims at reducing the *life-cycle impacts* of a product, even if it increases the net emissions from the waste management.

The direct emissions from landfills continue being a major source of greenhouse gases till 2020 despite the fact that only 28% of the municipal waste is assumed to be landfilled in 2010. This is due to the delay of methane emissions from landfill. Because of the rate of decay of waste with biodegradable contents, methane emissions will occur for several years after the waste was landfilled (the first order decay model presented in section 5.3). Hence, the results shown are the emissions occurring in the specific year, not the total emissions resulting from the amount of waste landfilled that specific year. The direct and avoided emissions are shown in Table 7.1.

But, as a counterweight, the increase in recycling leads to a rapid increase in the avoided emissions, from recycling of waste.

As for the estimation of emissions from recycling, we have taken a global approach. This implies that both direct and avoided emissions from recycling are ascribed to the country that generates and collects waste for recycling. Thus, even though the recycling or the manufacturing of materials may not physically take place in the country, or even within the EU for that matter, the emissions are still considered as arising in (or allocated to) the country[15]. In practise however, when a country exports waste for recycling, the emissions from the recycling process are not included in the export country's GHG emission and neither are emissions from manufacturing of materials or products that are imported and will become waste at a later stage. Hence, the model reflects the GHG emissions and savings *caused* by the EU-27 + Norway and Switzerland, regardless of where these emissions arise. This approach is different from the approach taken in the countries' reporting of GHG emissions to the UNFCCC. Furthermore, the model does not take into account that the emission factors from the treatment of waste exported to countries outside the EU-27 + Norway and Switzerland may be different.

Another interesting finding is that the collection and transport of waste accounts for less than 5% of estimated GHG emissions, and is therefore not an important contributor to the climate change effect of the waste management system. However, GHG emissions are only one indicator among several to describe environmental pressures. In a broader environmental context, pressures such as particles, noise or accidents may make transport a more significant contributor.

The GHG emissions from the management of municipal waste in the EU-15 + Norway and Switzerland and the EU-12 are shown in Figures 7.2 and 7.3.

We have estimated that the net GHG emissions in the EU-15 + Norway and Switzerland will decrease even further than in the EU-27 + Norway and Switzerland, thereby reinforcing the contribution of better waste management to the reduction of GHG emissions beyond the waste sector itself. As is the case of the EU-27 + Norway and Switzerland, the direct emissions from landfill remain high as a result of the delayed methane emissions. However, as recycling is assumed to increase to around 52% in 2020, the avoided emissions are expected to offset the direct emissions from landfill and recycling. The net emissions from incineration are also negative, thus contributing to the offsetting, but lower than recycling.

The net greenhouse gas emissions in the EU-12 are also estimated to decrease although not quite as fast as in the EU-15 + Norway and Switzerland. Again, the main source are the direct emissions from landfill even though we assume that landfill will decrease from 92% in 2005 to 66% in 2020. Recycling increases to 28% and incineration to 6%. Since the recycling share increases faster in EU-15 + Norway and Switzerland, given the fact that the avoided emissions from recycling are decisive for the overall net emissions, a faster decrease in the net emissions is observed in EU-15 + Norway and Switzerland than the EU-12.

[15] The ETC/SCP has analysed waste trade data from Eurostat and has concluded that in some waste fractions (e.g. paper), the GHG emissions (direct or avoided) actually taking place outside the EU are quite significant. For waste paper it is up to 20%.

Figure 7.2 **Net greenhouse gas emissions from municipal waste in EU-15 + Norway and Switzerland (million tonnes CO_2-equivalents per year)**

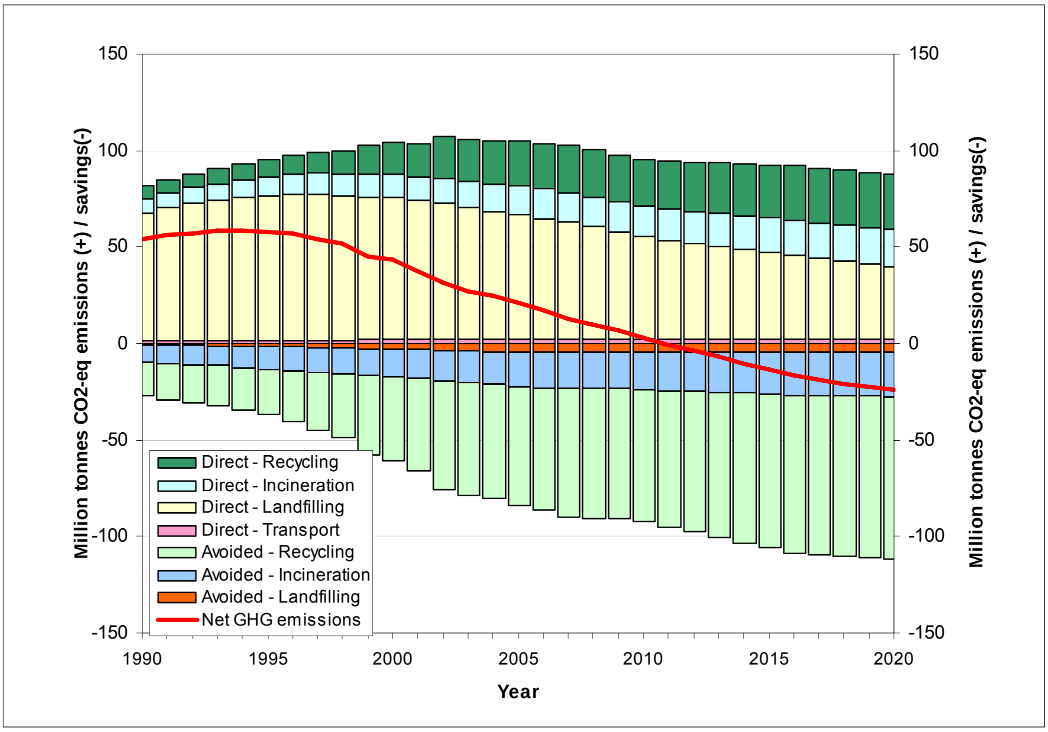


Figure 7.3 **Net greenhouse gas emissions from municipal waste in EU-12 (million tonnes CO_2-equivalents per year)**

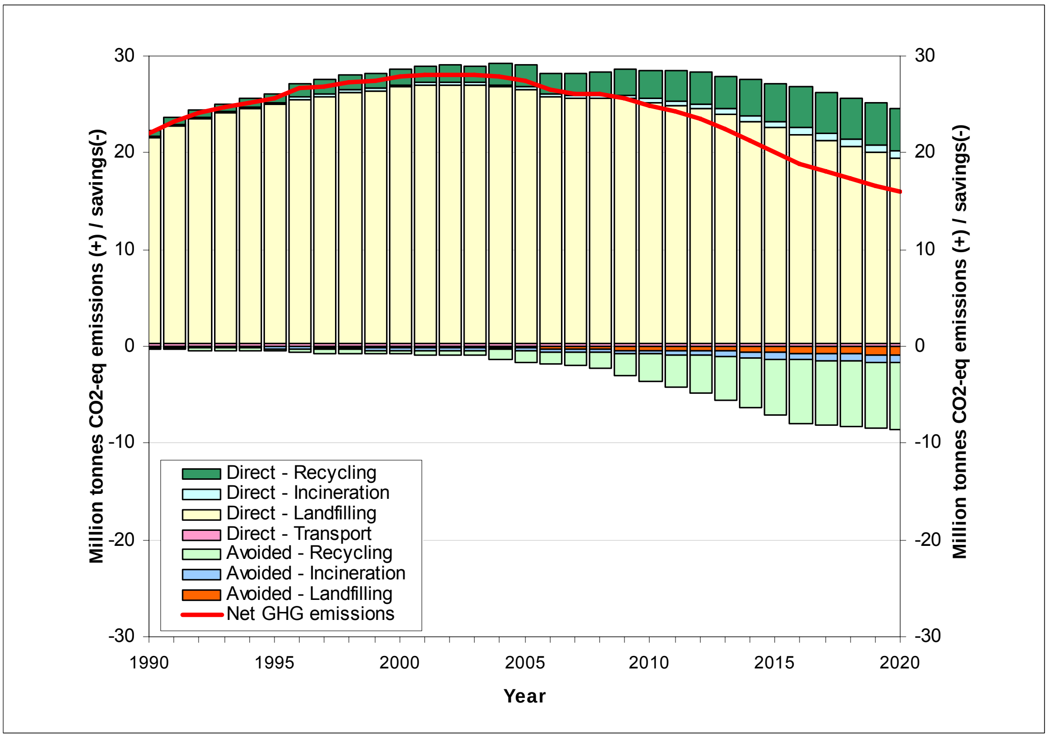


Table 7.1 Net emissions of greenhouse gases for the waste management options and transport in million tonnes CO2-equivalents, EU-27 + Norway and Switzerland

Treatment	Type	1990	2000	2010	2020
Landfill	Direct	87	101	78	57
	Avoided	-1	-3	-5	-6
Incineration	Direct	8	12	17	20
	Avoided	-9	-15	-20	-24
Recycling	Direct	7	18	27	33
	Avoided	-18	-44	-71	-92
Transport	Direct	2	2	2	3
Total	**Net GHG**	**76**	**71**	**28**	**-8**

Note: The figures have been rounded off, and may not add up exactly to the total.

The net emissions of greenhouse gases in each country are shown in Table 7.2 and 7.3 for the years 2005, 2010 and 2020. In several countries the net emissions from the waste management system will become negative, i.e. more emissions are avoided than generated, provided that the estimations are reasonable. These results on the national level should be interpreted carefully as several assumptions are not country-specific, but general for the EU-27 + Norway and Switzerland.

Table 7.2 Net emission of greenhouse gases in the EU-15 + Norway and Switzerland, 2010 and 2020 in thousand tonnes CO_2-equivalents

	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	CH	NO	EU-15+
2005	-377	-492	-5274	-806	6250	923	1782	1334	261	7071	21	-338	754	-409	9635	332	466	20336
2010	-993	-906	-8664	-628	2993	604	1166	784	300	4055	19	-925	1479	-621	3723	432	129	2386
2020	-1445	-1226	-11207	-916	-1581	143	-298	275	-218	-518	-3	-1620	1280	-1092	-5633	352	-432	-24061

Note: Data in the table have been imported from an Excel sheet, and should be interpreted with care. The aim is to show a trend, not to predict an exact amount.

Table 7.3 Net emission of greenhouse gases in the EU-12, 2005, 2010 and 2020 in thousand tonnes CO_2-equivalents

	BG	CY	CZ	EE	HU	LT	LV	MT	PL	RO	SI	SK	EU-12
2005	4124	N/A	3596	453	2561	929	500	57	8984	5128	271	890	27492
2010	3782	N/A	3418	412	2147	805	462	91	7601	5187	168	834	24907
2020	2308	N/A	2752	92	1507	548	217	104	5282	2884	37	217	15947

Note: Data in the table have been imported from an Excel sheet, and should be interpreted with care. The aim is to show a trend, not to predict an exact amount.

7.1. Greenhouse gas emissions per treatment option

In an attempt to investigate more thoroughly the details of the aggregated net GHG emissions, an analysis on the GHG emissions per treatment option would be useful. The relative role of each treatment option within the overall picture would indicate the focus points of the waste management system, where further improvement is necessary and which the policy initiatives should target.

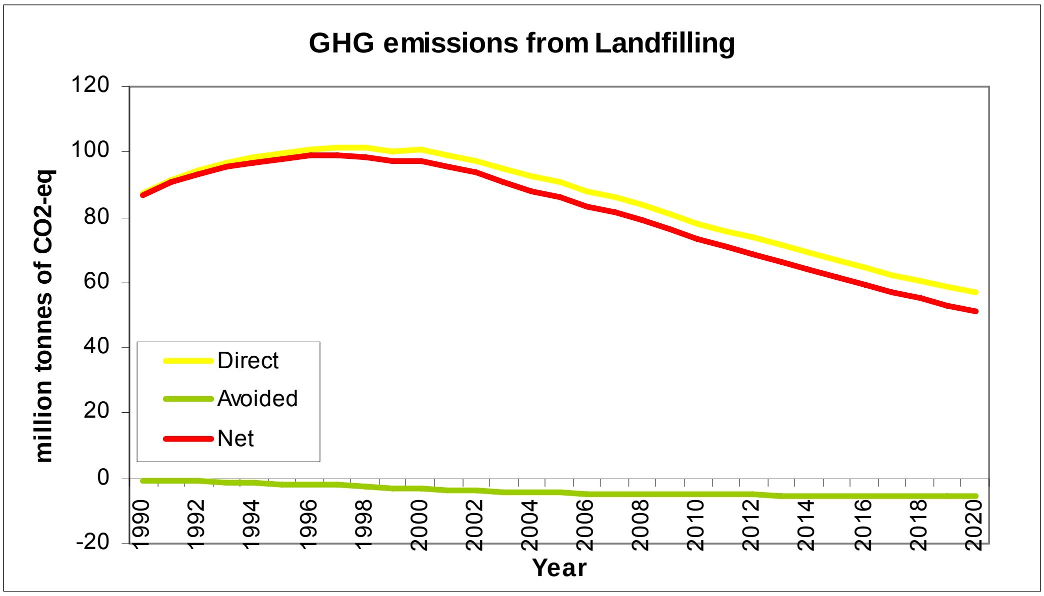
7.1.1. Greenhouse gas emissions from landfills

The GHG emissions associated with landfilling processes are shown in Figure 7.4. The direct emissions of landfilling are the highest among all treatment options, mainly because of methane emissions. Methane has a much higher impact potential on global warming than carbon dioxide.

Moreover, landfilling has the unique property of time delay effects. This means that waste landfilled in a specific year would emit methane for many following years. Therefore, the actions taken against landfilling practices will show their effects on GHG emissions a long time after their implementation. Therefore, despite the relatively drastic measures taken from 2000 on, direct emissions are decreasing, but almost linearly.

Another interesting finding is that the avoided emissions from landfilling are rather insignificant compared to the direct emissions. The improvements in technological efficiencies, as well as the installation of methane recovery equipment to an increasing number of landfills may increase the avoided emissions, but the potential for global warming mitigation from energy recovery from methane is limited. Of course, this issue is strongly related to the assumptions made around methane recovery rates (see also chapter 5.3.1).

Figure 7.4 Greenhouse gas emissions from landfilling in EU-27 + Norway and Switzerland (million tonnes CO_2-equivalents)



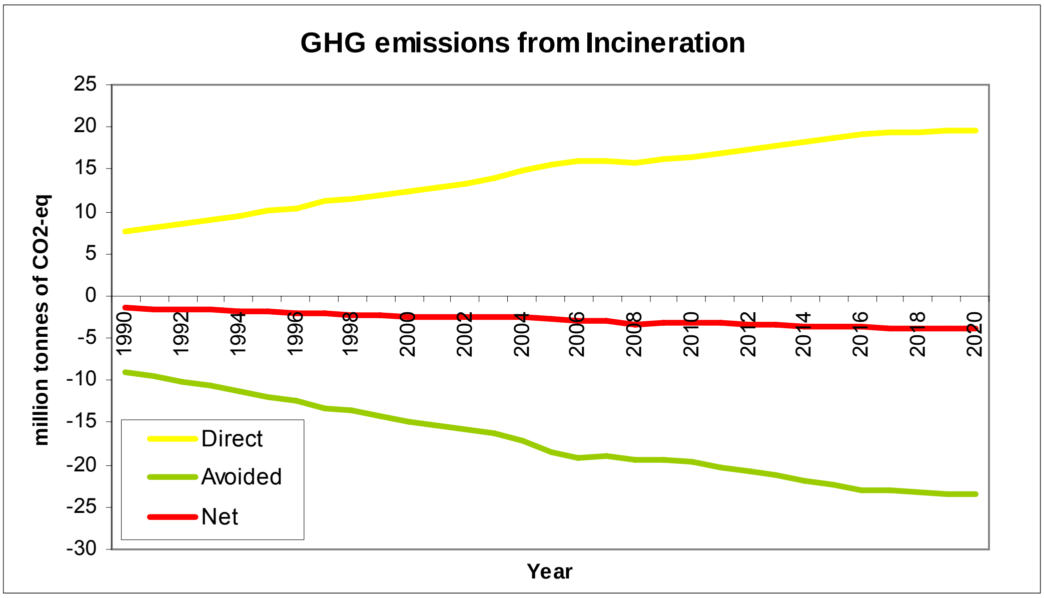
7.1.2. Greenhouse gas emissions from incineration

The GHG emissions from incineration are illustrated in figure 7.5, broken down to direct and avoided emissions. The direct and indirect emissions appear to be almost symmetrical, cancelling each other out. Therefore, the net emissions from incineration approximate zero.

The reason for this picture lies in the current set of assumptions established in this model. The outcome of these assumptions is that the incineration share does not change significantly over the years. On the other hand, the incineration efficiency, the used or replaced energy mix and the incinerated waste composition are assumed to remain constant throughout the modelled time period (1990-2020). Therefore, the incineration emissions are only affected by the changes in treated quantities, which affect equally both the direct and the avoided emissions.

The observed stability of the net emissions and their approximation to zero render incineration as the least important contributor to the overall emissions and avoidance potential. However, if the set of assumption changes (e.g. energy mix time development is taken into account), then the incineration effect might change significantly.

Figure 7.5 Greenhouse gas emissions from incineration in EU-27 + Norway and Switzerland (million tonnes CO_2-equivalents)



The assumption that the selected replaced energy mix due to incineration remains stable for each country for the entire modelling period, could be critical for the overall results and the specific conclusions for incineration as a treatment option, because of EU policies to reduce GHG emissions and moving to renewable energies. Therefore, the future avoided emissions, especially in the end of the modelling period in 2020, are expected to be lower than currently. The GHG benefits showed for the projected MSW management could be thus overestimated.

The ETC/SCP has therefore carried out a sensitivity analysis where the avoided emissions from both recovered electricity and heat through incineration are halved. Table 7.4 below shows the absolute (in Mt of CO_2-eq) and percentage change between the baseline scenario and the simulation with 50% less GHG emissions from primary energy production in 2020. The table shows that the 50% decrease in avoided emissions from incineration would reduce the overall avoided net emissions by 11-12 % and thus have a limited effect on the overall results.

Table 7.4 Comparison of baseline scenario's overall results to a simulation with 50 % lower avoided emissions from incineration

Year	**emissions from avoided energy production (Mt CO2-eq) – with 50% less GHG**	**Baseline Model (Mt CO2-eq)**	**Absolute difference (Mt)**	**Difference (%)**	**Avoided emissions with 50% less GHG emissions from avoided energy production (Mt CO2-eq)**	**Avoided emissions - Baseline model (Mt CO2-eq)**	Difference (%)
2020	5.78	-8.19267	13.98	-170.58%	-106.76	-120.73	-11.58%

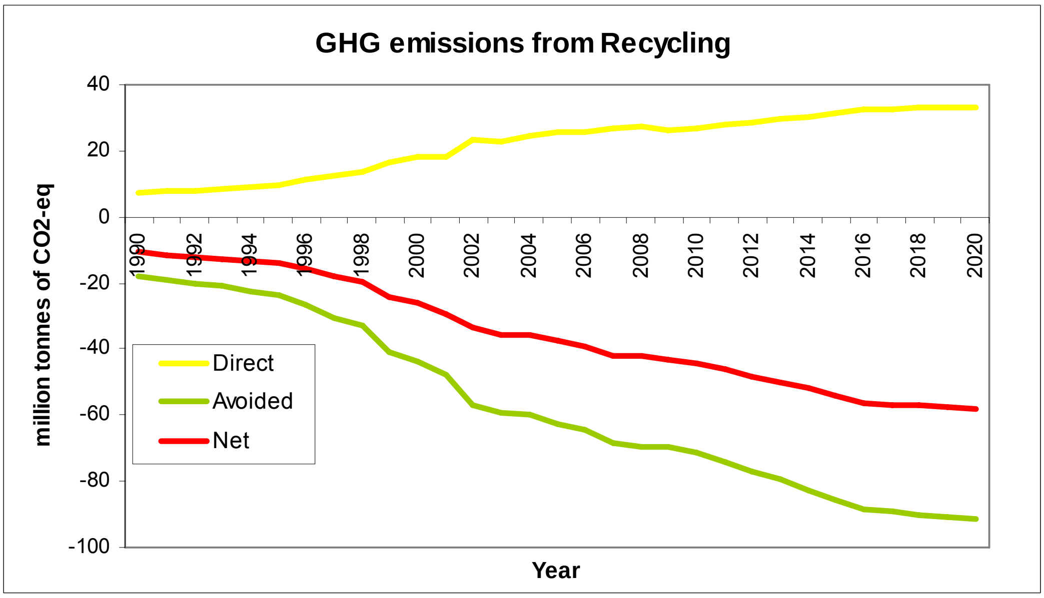
7.1.3. Greenhouse gas emissions from recycling

The recycling-related GHG emissions, as seen in figure 7.6, present the reverse picture than landfilling. There is an increase observed in the direct emissions, but a much more rapid increase (in absolute terms) follows for the avoided emissions.

The increasing recycled quantities logically lead to increasing direct emissions related to the waste treatment. However, all recycled fractions' data show higher avoided emissions than direct ones. Therefore, the increase in recycling share leads to a rapid decrease of the net emissions.

The order of magnitude of the avoided emissions was not sufficient to overcome the landfilling direct emissions in the beginning of the modelled time period. However, around 2011, the avoided emissions from recycling manage to "offset" the direct emissions from landfilling. In fact, in the end of the projection period, the avoided emissions from recycling manage to offset more than 83% of all direct emissions from the MSW management. This is not a legitimate comparison, since the quantities treated in each option are different, but it gives a useful input to policy making, since the benefits from recycling are decisive for the net overall emissions formation. The avoided emissions from recycling constitute more than 75% of the total avoided emissions. It is safe to say that *recycling is mainly responsible for the rapid decrease in the MSW net GHG emissions after the year 2000.*

Figure 7.6 Greenhouse gas emissions from recycling in EU-27 + Norway and Switzerland (million tonnes CO_2-equivalents)



8. Alternative scenarios

The results from the baseline scenario describe the situation in the European municipal waste management systems. However, the future development of the systems is greatly uncertain, since it is based on assumptions or qualified estimations.

In the baseline scenario, future waste treatment does not necessarily comply with the current legislation within the EU. Instead, the countries' historical behaviour regarding treatment options, as expressed through registered data, is used as an indication for future trends.

Moreover, the baseline scenario does not examine the waste management's *potential* for global warming mitigation. It would therefore be interesting to estimate possibilities for mitigation based on an increased effort by countries to comply with the EU waste legislation or further amendments in the future.

For these purposes, two alternative scenarios have been constructed: they examine the results of: (a) full implementation of the Landfill Directive and (b) the consequences of an assumed *total* landfill ban applied to all EU-27+ Norway and Switzerland.

8.1. Full compliance with the Landfill Directive's diversion targets (LD scenario)

This scenario explores the effects of full compliance with current legislation by all countries with the targets set by the Landfill Directive (Directive 99/31/EC). There are more relevant pieces of legislation within the waste sector such as the revised Waste Framework Directive (Directive 2008/98/EC) and those targeting specific waste streams such as the WEEE Directive, the Batteries Directive and especially the Packaging Directive. For these three latter directives, however, the targeted streams are not specifically from municipal origin. It is difficult and very uncertain to translate the targets set by these Directives into municipal waste targets. This exercise would have to be based on many assumptions regarding, for example, the amount of municipal origin within the packaging waste.

The Waste Framework Directive includes targets for the recycling of specific waste materials stemming from households, which is a major part of the municipal waste stream, but the waste from households is not equal to the total amount of MSW. Since there is no indication about the generation nor the recycling **composition** for many countries regarding how much of the MSW is coming from households and how much is coming from other sources, it is impossible to assume compliance with this Directive without high uncertainty. This uncertainty would subtract the credibility of the results rendering the outcome less reliable. Moreover, the objective in the Waste Framework Directive to reduce waste generation has not been taken into account neither as it is not a quantified target.

The targets set in the Landfill Directive refer to three threshold years, 2006, 2009 and 2016. Countries need to gradually reduce the amount of biodegradable waste going to landfill, according to specific reduction targets in each of the threshold years. Each country is obliged to:

1. Reduce the amount of biodegradable municipal waste landfilled by 2006 to 75% of the quantity generated in 1995.
2. Reduce the amount of biodegradable municipal waste landfilled by 2009 to 50% of the quantity generated in 1995.

3. Reduce the amount of biodegradable municipal waste landfilled by 2016 to 35% of the quantity generated in 1995.

The countries that landfilled more than 80% of their MSW in 1995 had the right to apply for a derogation period of a maximum of four years for each target. Eleven countries have been granted a derogation period: Bulgaria, Czech Republic, Estonia, Greece, Ireland, Latvia, Lithuania, Poland, Romania, Slovakia and the United Kingdom (EEA, 7/2009).

The baseline projections model does not assume the full implementation of the Landfill Directive, as mentioned earlier. The treatment shares are estimated based on an extension of the historical trends, reinforced by the existing or planned legislation. According to the projected shares, only 8 Member States would fulfil the Landfill Directive's targets for diversion of biodegradable municipal waste from landfill: Austria, Belgium, Denmark, France, Germany, Luxemburg, the Netherlands and Sweden. Switzerland is not bound by EU legislation, but it has implemented a national landfill ban on biodegradable waste. Therefore, there is no difference between the results of the baseline scenario and the Landill Directive scenario for CH. Norway, although not a part of the EU, has ratified the Directive and is also expected to meet the diversion targets.

Many of the Member States would not comply with the targets set for any of the threshold years 2006, 2009, 2016. This is in no way a forecast of the actual fulfilment probability of the targets by these countries and should not be read like that, as the baseline scenarios do not take into account any current or future activities that would alter the historical trends and could contribute to countries' fulfilment of the targets.

According to the November 2009 communication document by the European Commission, the practical implementation of the Landfill Directive "remains highly unsatisfactory" (EC, 2009). The supporting report from May 2009 published data on the monitoring of the biodegradable municipal waste going to landfills (EC, 2009). By analysing the data, safe conclusions about the fulfilment of the 2006 target can be drawn for nine countries: Austria, Denmark, Finland, France, Germany, Italy, Luxembourg, the Netherlands and Portugal (countries with derogation periods are excluded). All these countries reported to have met the 2006 target. According to our model, all these countries met the 2006 target as well, except for Italy. The GHG model does not include changes on the landfilled waste composition over time, since there is no data availability and the uncertainty of such an attempt would be very high. This is the reason that, although the model uses the reported landfill share, it produces different results from what Italy reports regarding the Directive's targets. This inconsistency for Italy will remain, as there is no available data describing the inert fractions quantities in the Italian landfills. Moreover, the goal of this study is not to monitor the fulfilment of the Landfill Directive, but to calculate the GHG emissions associated with MSW management. The compositional difference between the model and the reported amounts does not provoke large differences in the results, since the methane emissions from landfills are largely regulated by quantities landfilled during an extensive time period. The organic waste diverted from landfills, in any case, increases the avoided emissions of the system through added energy (if incinerated) or material (if composted) recovery. Therefore, the simulation of waste management for Italy will produce more conservative results than if the reported amounts had been used.

The baseline scenario forecasts that (by also taking into account the derogation periods for the relevant countries):

- AT, BE, CH, DE, DK, FR, LU, NL, NO, SE would comply with all stages of the Landfill Directive according to the baseline scenario
- SI, LT would fulfil the two first targets but fail the third for 2016 and 2020 respectively.

- BG, EE, ES, FI, HU, PT and UK would only fulfil the first target for 2006 (or 2010 in case a derogation has been granted).
- The rest of the EU – 27 would not comply with any target of the Landfill Directive[16]

In the LD simulation of the model, the assumptions related to treatment options' shares that cause the above developments need to be modified so that all countries fulfil the biodegradable municipal waste reduction targets, by also taking into account the derogation periods granted to some countries. The landfill share development, as well as the landfilled waste composition, ideally, need to be revised. Another assumption refers to the diverted waste from the landfill that need to be treated in a different way.

The simulation of meeting all the targets in the greenhouse gas model is quite complex, as many decisions should be made and further translated into assumptions of the simulation. One reason is that the targets are related to biodegradable municipal waste whereas the model uses total municipal waste. The scenario assumes that the reduction of the biodegradable fraction going to landfill is achieved through the reduction of the overall landfill share. The reasoning behind this choice is that countries would put more effort into sourcing separate organic waste. Therefore, it is reasonable to assume that the non-biodegradable separated waste would be diverted from the landfills as well. It is the landfilled mixed waste fraction that will be reduced. As a result, more waste will be diverted to the recycling and incineration route. A simple assumption has been adopted for this case, namely that the waste diverted from landfill will be rerouted *equally* to incineration and recycling.

After the maximum allowed landfilled percentage for each target year is established, the resulting landfill share is calculated. The determination of the landfill share is based on a trial-and-error process so that the maximum share is estimated, which produces landfilled biodegradable quantities that do not exceed the Directive's targets. The share in-between the target years decreases linearly, while after 2016 the landfill share remains constant.

Under these assumptions and for countries with no derogation period, the model includes the following assumptions:

- For the countries that do not fulfil the 2016 target in the baseline scenario, action for reducing the landfill share is assumed to be taken from 2010 (the year following the deadline for the second target)
- For the countries that do not fulfil the 2009 target in the baseline scenario, action is assumed to be taken from 2007 (the year following the deadline for the first target)
- For the countries that do not fulfil the 2006 target in the baseline scenario, action is assumed to be taken since 2001

Under these assumptions and for countries with derogation period (a derogation period of 4 years for all the relevant countries is assumed), the regulation of the model includes:

- For the countries that do not fulfil the 2020 target in the baseline scenario, action is assumed to be taken from 2014 (the year following the deadline for the second target)
- For the countries that do not fulfil the 2013 target in the baseline scenario, action is assumed to be taken from 2011 (the year following the deadline for the first target)

[16] The fact that landfilled waste composition is assumed to remain constant may create a false image for some countries that put effort in reducing only the landfilled organic waste and the baseline model might overestimate the landfilled organic waste quantity.

- For the countries that do not fulfil the 2010 target in the baseline scenario, action is assumed to be taken since 2005.

Figure 8.1 and table 8.1 present the results of the simulation. Compared to the baseline scenarios, the results obtained for a full Landfill Directive compliance are more environmentally sound. The savings from the increase in recycling and incineration, as well as the decrease of landfill's direct emissions lead to a steeper slope of the net GHG curve. The final projected GHG emissions in 2020 are estimated to be approx. -26 million tons of CO_2-equivalents or a total net reduction from 1990 to 2020 of 102 million tons of CO_2-equivalents. Further emissions' reduction is expected to occur after 2020 since the landfill share reduction has a delayed effect on GHG emissions due to the slow degradation rate of the biodegradable waste: the waste landfilled prior to the landfill share reduction emits methane for many following years.

According to the analysis presented in chapter 7, the diversion of waste away from landfill and towards recycling are the two actions that produce the highest benefits for the GHG emissions. The full implementation of the Landfill Directive facilitates this shift, a fact that can be deduced by observing the GHG emissions development. The baseline scenario projects a decrease in GHG emissions from around 70 to -8 million tons of CO_2-equivalents in the period 2000-2020, namely a 78 million tonnes reduction (before 2000, the baseline scenarios and the Landfill Directive scenarios are identical).

In the same time period, the Landfill Directive scenario is estimated to achieve an average 96 million tonnes of relative decrease, namely 23 % further decrease than the baseline scenario.

It is difficult to assess the realistic added value of the Landfill Directive on national municipal waste management systems, since a clear trend to avoid landfilling was observed even before the Landfill Directive ratification in some countries. However, even if this trend, modelled in the baseline scenario, leads to a significant global warming mitigation potential, this potential is much inferior than if all countries fulfilled the Directive. This increased potential should work as an extra incentive for the countries to intensify their efforts on implementing the European legislation, since they would synergistically move towards meeting their binding greenhouse gas reduction targets.

Figure 8.1 Net greenhouse gas emissions from municipal waste in EU-27 + Norway and Switzerland, assuming full compliance with the Landfill Directive (million tonnes CO_2-equivalents)

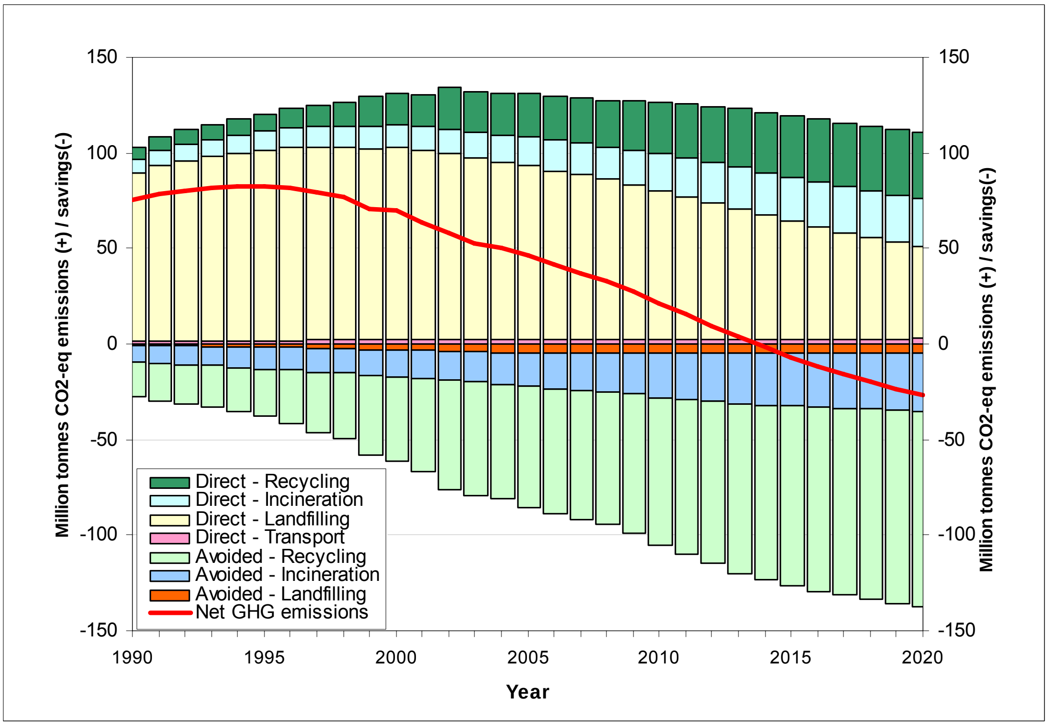


Table 8.1 Net emissions of greenhouse gases in the EU-27 + Norway and Switzerland according to the baseline scenario and the LD scenario in million tonnes CO_2-equivalents

	2006	2009	2012	2016	2020
BS	43.74	32.21	19.58	2.08	-8.19
LD	41.24	27.75	9.69	-11.62	-26.49
Difference	-2.49	-4.46	-9.89	-13.69	-18.29

Note: the green years are the target years of the Landfill Directive without derogation
BS = baseline scenario
LD = 'Full compliance with Landfill Directive' scenario

8.2. Compliance with a hypothetical total landfill ban (LB scenario)

Landfilling is the most intense activity within the municipal solid waste management system in terms of global warming potential contribution. The emitted methane affects global warming 25 times more than carbon dioxide per unit of mass (IPCC, 2007).

Whereas the EU Landfill Directive requires all countries to eventually reduce landfilling of biodegradable municipal waste to 35% of the levels generated in 1995, some countries have already started or are planning to implement a total ban of landfilling (biodegradable) municipal waste and thus go beyond the EU Landfill Directive. The purpose of this scenario is to show the effect of a hypothetical total landfill ban on all fractions if it would be applied in all countries.

A hypothetical total landfill ban would not only reduce drastically the emissions of landfills compared to the baseline scenario, but it would also result in an increase of the use of other treatment options, given a stable or growing waste generation. Since incineration and mainly recycling have large saving potentials for GHG emissions, the landfill ban would indirectly increase the GHG savings from waste management. The sum of these two beneficial outcomes would produce a quite high mitigation potential for the entire MSW management.

In this simulation, a hypothetical landfill ban is imposed on the EU-27 + Norway and Switzerland from 2020 (zero deposition in 2020). The baseline projected landfill share starts decreasing gradually from 2011 until it reaches zero in 2020. However, some countries exhibit rather high landfill shares in 2010 and the linear reduction to zero would require extreme political will and strict measures. The reader should keep in mind that this scenario does not propose a realistic approach to modern waste management, it rather attempts to examine the potentials instead.

The generation of waste in the landfill ban (LB) scenario is identical to the baseline scenario. Therefore, any reduction of the landfill share leads to waste quantities unaccounted for. This fact requires the introduction of a new assumption, common for all countries, although the diversion of the excess quantities relates to country-specific national policies, but also to the potential implementation of new overall strategies that might alter the relevant management system. Since the LB scenario aims at demonstrating the potential benefits of an ideal system, a simple assumption has been chosen: the waste quantities diverted from landfill are equally distributed to the other two alternatives, namely incineration and recycling. This is the same approach as has been taken for the 'full compliance with the Landfill Directive' scenario.

Figure 8.2 illustrates the development of GHG emissions over time with a landfill ban applied. The differences to the baseline scenario can be seen from 2010 when the course towards a landfill ban begins. In table 8.2, the difference is shown between the net GHG emissions of the baseline and LB scenarios.

In the landfill ban case, the results of the simulation show only somewhat higher overall net GHG savings than the Landfill Directive scenarios, in spite of a *total* landfill ban imposed in the case of the LB scenarios. This fact is justified by the increased benefits that stem out of the increase of the recycling share for the Landfill Directive scenarios. But the most interesting conclusion refers to the biodegradable fraction of municipal waste. The reduction of the biodegradable fraction causes most of the differences compared to the baseline scenario.

More analytically, the difference in landfilled *quantities* of biodegradable waste between the LD and the LB scenarios is not very large. The maximum allowed landfilled quantities, according to the Landfill Directive are small (35% of the biodegradable waste generated in 1995, when waste generation was significantly lower), so the consequences to the direct emissions are similar. Moreover, the diversion of waste has a delayed effect on the landfill direct emissions because of the timelag for the degradation of waste which emits methane for many years after the waste has been landfilled. Additionally, many countries (including some large ones, e.g. Germany, with significant a contribution to the overall results) have taken measures to reduce drastically the landfilled biodegradable municipal waste. For these countries, the LD and the LB scenarios are quite similar as well.

The fact that the diverted quantities are distributed to the other options in the same way for both LD and LB scenarios, functions as a stabilising parameter, not allowing the net GHG emissions to fluctuate greatly. Recycling has a major effect on the overall results and the recycled quantities are rather similar for both the LD and the LB scenarios.

Figure 8.2 Net greenhouse gas emissions from municipal waste in EU-27 + Norway and Switzerland with a landfill ban (million tonnes CO_2-equivalents)

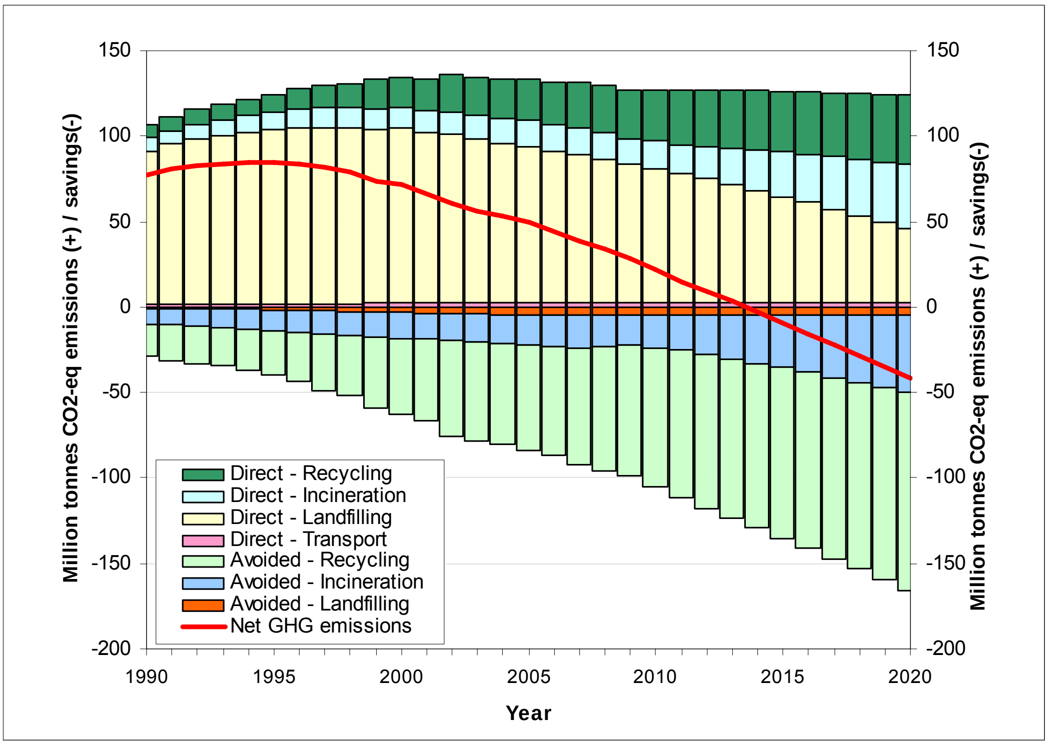


Table 8.2 Net emissions of greenhouse gases in the EU-27 + Norway and Switzerland according to the baseline scenario and the landfill ban scenario in million tonnes CO_2-equivalents

	1995	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BS	83.75	27.85	23.63	19.58	15.34	10.86	6.46	2.08	-0.70	-3.32	-5.79	-8.19
LB	83.75	21.79	14.85	9.29	3.35	-2.87	-9.16	-15.48	-21.89	-28.44	-35.06	-41.81
Diffe-rence	0	-6.06	-8.78	-10.29	-11.99	-13.72	-15.62	-17.56	-21.19	-25.11	-29.27	-33.61

BS = baseline scenario
LB = 'Landfill Ban' scenario

The reduction of the landfill share and the resulting simultaneous increase of recycling and incineration have a two-fold effect on GHG emissions: methane emissions are reduced (these cover most of the contribution to the overall direct emissions) and the benefits from recycling and incineration increase. Since the **net** emissions from incineration and especially recycling are generally lower than from landfilling (more or less according to each individual waste fraction), a reduction of landfilled waste leads to a decrease of the aggregated net GHG emissions.

Table 8.2 is explicit in the sense that the observed difference between the BS and LB scenarios is quite large. Especially in 2020, when the landfill ban is assumed to be fully implemented, the difference lies around -34 million tons of CO_2-equivalents. The mitigation potential is important as the GHG savings potential in this ideal configuration of EU-27 + Norway and Switzerland waste management would raise to net emissions of almost -42 million tonnes CO2-equivalents for 2020, showing that more ambitious waste policies can contribute significantly to the target to further reduce overall GHG reductions.

The quite important global warming mitigation potential illustrated in this chapter cannot be realistically exploited by 2020. Given the problems the countries have with implementing the Landfill Directive (see previous chapter), it is entirely unrealistic to expect the application of a landfill ban by 2020. However, the mitigation potential is demonstrated and its partial or full exploitation depends on policy-making processes and resources restrictions.

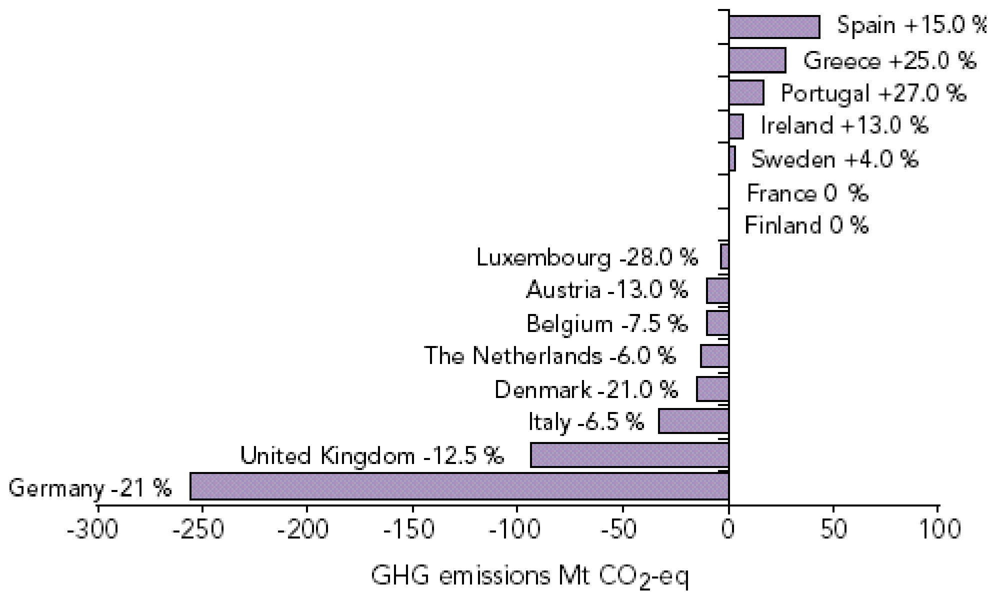
9. Waste management contribution to GHG emission reduction targets

9.1. Kyoto Protocol

Under the Kyoto Protocol, the EU-15 has taken on a common commitment to reduce emissions by 8 % on average between 2008 and 2012, compared to base year emissions. This implies a reduction of about 340 million tonnes by 2012 compared to 1990. Within this overall target, differentiated emission limitation or reduction targets have been agreed for each of the 15 pre-2004 Member States under an EU accord known as the 'Burden-sharing Agreement' (see figure 9.1 below).

The Kyoto protocol has also introduced the “flexible mechanisms” which help the countries to meet their targets without resolving to physical reductions of their domestic emissions. The flexible mechanisms include the CDM and the JI projects as well as an emission trading scheme. EU15 therefore, can reach the target of 8% without applying measures for the physical reduction of GHG emissions that would cover the entire 8%.

Figure 9.1 Greenhouse gas emission targets of EU Member States for 2012 relative to base-year emissions under the EU burden-sharing decision



Source: EEA, 2003

The Kyoto protocol has adopted the accounting protocol used by the UNFCCC reporting. The waste management is divided into fractions which are registered under sectors according to the IPCC recommendations. According to the IPCC Guidelines, the waste sector is composed of 'solid waste disposal on land' (landfills), 'wastewater handling' (anaerobic digestion) and 'waste incineration' (without energy recovery). Other emissions related to the waste management, such as emissions from recycling are reported under the industrial sector, emissions from incineration with energy recovery and emissions from waste collection activities (transport) are reported in the energy sector. A distinction between fossil and biogenic CO2 emissions is also made.

In this paper, a different, life-cycle based perspective is taken, looking at the waste management **system** – including the activities for which emissions are reported in the energy sector and the industrial sector. The waste management system includes all processes/activities that are a direct or indirect consequence of the objective to treat the waste in an integrated manner. In this perspective, the full implications of waste management are taken into account (e.g. credits for recovered energy are attributed to waste management, not the energy sector), the avoided emissions are accounted for and a more clear image emerges of what waste management totally can contribute to reducing GHG emissions and possibly to meeting the targets of the Kyoto protocol.

The MSW management system is involved both in physical emission accounting schemes within the EU15 and in flexible mechanisms. The allocation of the benefits (GHG emissions reduction) is rather complicated. Moreover, some parts of the waste treatment take place outside the physical borders of the EU15. However, the analysis in this chapter assumes that all reductions achieved by better European MSW management are attributed to the EU15[17]. The fact that the EU15 might meet the Kyoto target without being based entirely on physical emission reductions, but with exploiting CDM and JI instead, makes the association of MSW related emissions reduction to the Kyoto target slightly inaccurate. Therefore, the MSW potential for a contribution to the Kyoto target should be interpreted as an indication only, although MSW related emission reductions will happen under all circumstances, because the reductions are achieved due to the requirements of better MSW management and not initiatives taken because of the Kyoto target.

EU15 (EU member states before 2004) committed to reduce their GHG emissions by 8% by 2012 compared to the emissions of 1990. According to the scenarios presented in this paper, the **minimum** mitigation contribution of municipal waste management is 49 Mt CO2-eq in the baseline scenario (see table 9.1 below). This corresponds to **1.16%** of the base year emissions (4,266 Mt CO2-eq), which is a substantial part of the overall target of 8% reduction equivalent to about 340 Mt CO2-eq. This estimation becomes even more significant, as only municipal solid waste, around 8-9% of total waste in the EU, is included in the model.

Table 9.1 GHG emissions from MSW management in the EU15 in 1990 and in the Kyoto period (2008-2012) divided into direct and avoided emissions in million tonnes CO_2-equivalents

Baseline Scenario	Year	Direct Emissions	Avoided Emissions	Net Emissions	Difference 1990 to 2008-2012 average	% of Base Year Emissions
	1990	77.28	-25.48	51.80	49.45	-
	2008-2012 average	92.14	-89.78	2.35		1.16%

The main share of this mitigation potential is realised through savings due to replacing virgin materials with recycled materials and energy from conventional sources with waste-derived energy. The sectors producing virgin materials and energy thus benefit from better waste management in a way that it makes it easier for them to reduce GHG emissions than without these waste management measures.

In fact, it becomes clear from table 9.1 that the changes in the avoided emissions are responsible for this mitigation potential. The direct emissions from the system have actually increased by around 19%, while the avoided emissions have increased (in absolute num-

[17] The life-cycle perspective does not take into account the geographical location of the processes, it rather focuses on the decisions responsible for the development of the processes. In other words, the improvement of the MSW management in EU15 is a consequence of policy decisions/actions of the EU15. Therefore, the benefits stemming from these actions should also be allocated to the EU15.

bers) by more than 3.5 times. The decrease of around 64 million tonnes of CO_2-eq in the avoided emissions is explained mainly by increased recycling, since recycling activities account for around 50 million tonnes of the total decrease, i.e. 78%. Therefore, the very important role of recycling is quite clearly demonstrated. *In fact, in terms of climate change mitigation, the goal of waste management should be to promote further the recycling schemes*.

The increase in direct emissions during the 1990-2012 period can be explained by the increase in the total generation of MSW and the time delay effect of the methane emissions from landfills. The latter means that the reduction in the landfilled quantities (in that period, landfilling was reduced from 69% of all municipal waste generated to around 29% for the 2008-2012 period) creates benefits that will appear on the reporting several years later than when the actions are taken. The previously landfilled waste continues to emit significant quantities of landfill gas.

The Kyoto protocol accounting mechanism, as already mentioned, includes only a small part of the waste management system in the “waste sector”. Table 9.2 shows the distribution of the ETC/SCP model GHG results into IPCC-defined sectors. The reductions achieved in the waste sector are minimal, according to table 9.2. However, the benefits achieved by energy recovery (in UNFCCC reporting, these emissions are registered under the energy sector) and material recovery activities (in UNFCCC reporting, these emissions are registered under the industrial sector, except for composting emissions, which are reported under the agricultural sector) are quite significant. In fact the energy recovery-based reductions are comparable to the waste sector’s reduction. However, the recycling-based reductions are much more significant, achieving approximately 3.6 times larger reductions than the energy recovery does.

Table 9.2 GHG emissions from MSW management in the EU15 in 1990 and in the Kyoto period (2008-2012) correlated with the IPCC sectors in million tonnes CO_2-equivalents[18], as calculated in the baseline scenario

Year	Kyoto base year emissions	Emissions in IPCC waste sector	Avoided emissions from energy recovery (corresponding to IPCC energy sector)	Avoided emissions from material recovery (corresponding to IPCC industrial sector, agricultural sector)	Net emissions from waste management
1990	4266.00	63.66	-8.73	-16.75	51.80
2008-2012	-	52.25	-22.61	-67.18	2.35
Reduction/Base year emissions	-	0.27%	0.33%	1.18%	1.16%
Kyoto target	8%				8%

The EU-27 does not have any Kyoto target, since the Protocol was ratified before the 12 new Member States entered the EU. Therefore the EU-12 Member States have individual targets under the Kyoto Protocol (apart from Cyprus and Malta, which do not have any target).

9.2. The EU-27 target to reduce GHG emissions

In spring 2007, the European Council adopted the unilateral commitment to reduce EU-27 GHG emissions by 20 % in 2020 compared to 1990 levels. This target might be increased to 30 % provided that a Post-Kyoto-Commitment will be agreed on where other

18 The IPCC waste sector emissions do not include emissions from incineration with energy recovery, therefore the value presented refers only to direct emissions from landfilling.

developed countries commit themselves to comparable emission reductions and if economically more advanced developing countries will also contribute adequately.

In 2007, the EU-27 emitted a total of 5, 184 Mt CO_2-equivalent (Mt CO_2-eq.) greenhouse gases (including international aviation, excluding maritime transport and LULUCF[19]), a 7.9 % reduction compared to 1990 (5, 630 Mt $CO_{2\text{-eq}}$) (EEA, 2009).

To achieve the 20 % reduction goal for 2020, a reduction of 1 126 Mt $CO_{2\text{-eq}}$ is necessary for 1990-2020. This means still about 680 Mt $CO_{2\text{-eq}}$ have to be avoided between 2007 and 2020. Better waste management (reduction of direct emissions from the waste sector and reduction of emissions in producing industries via the use of secondary materials instead of virgin materials as well as the replacement of fossil fuels by energy from waste) can contribute with a reduction of 82 Mt CO_2-eq in the same time period, according to the ETC/SCP model's baseline scenario – which translates to around **1.46%** of 1990 emissions. As a part of this reduction potential is covered by the European Emissions Trading System (ETS), this potential cannot be added either to reductions achieved via ETS or reductions achieved through domestic measures. But the figures show the relevance of better waste management in fulfilling the targets to be covered by the ETS sectors.

Table 9.3 GHG emissions in the EU-27 in 1990 and in 2020 divided into direct and avoided emissions in million tonnes CO_2-equivalents

	Year	Direct Emissions	Avoided Emissions	Net Emissions	% of Base Year Emissions
Baseline Scenario	1990	99.65	-25.84	73.82	-
	2020	108.18	-116.31	-8.12	-
	Reduction 1990-2020	8.53	90.47	81.94	1.46%

In table 9.3, the division of the net emissions is presented for EU-27 for the period relevant to the EU2020 target. The same conclusions as for the Kyoto target can be drawn from this breakdown as well. The direct emissions from the management of MSW are expected to increase. However, the avoided emissions are estimated to increase (in absolute numbers) by approximately 4.5 times. Recycling again is mainly responsible for this development as it contributes the most to the avoided emissions – recycling is projected to cover around 80% of this development.

The potential for mitigation is not confined to the assumptions set by the baseline scenarios. If the scenario of a landfill ban is taken into account, emission reduction would move up to 115 Mt CO_2-eq which means a reduction of around **2.04%** compared to the base year.

9.3. Policy options for further GHG emissions reduction

At this point, it should be underlined that the reduction potentials mentioned in the previous chapter, only refer to municipal solid waste, which comprise 8-9% of the total waste generated quantity in the EU. Therefore, the entire European waste management system could be proven to be an important field for achieving fast, relatively low cost GHG emissions reductions (Prognos, 2008). On the other hand, a clear message from the aforementioned analysis is that recycling is the most important factor for achieving significant GHG emissions reductions. Consequently, there is a clear argument for further policies that promote more recycling of other waste streams as well.

[19] Land Use, Land-Use Change and Forestry

The process of setting long-term targets (as well as intermediate ones for monitoring) is quite effective regarding waste legislation (EEA, 7/2009). This report shows proven that, besides other environmental considerations, increasing recycling has an added value with respect to global warming mitigation. However, only around 40% of the total generated waste in the EU is regulated with respect to recycling (EEA, 2010). Therefore, the potential for setting recycling targets and moving towards a recycling society is still only partly exploited. The added value of global warming mitigation potential should function as an extra incentive to promote further recycling oriented policies.

10. Uncertainties and improvement options

The aim of the modelling is to show the likely future trends, not to predict exact amounts of waste generated or emissions of greenhouse gases. The model includes a wide range of parameters for waste quantities, waste composition, waste management, methane recovery, emission factors, etc. Some of these parameters are more uncertain than others. The results presented in this paper should therefore be interpreted carefully as the result may change if another set of parameters and assumptions is applied.

The model includes 28 countries which all have different waste management conditions, and for some countries it may have been easier to collect detailed information than for others. However, it should be kept in mind that the objective is to show the consequences for Europe, which is why many of the assumptions on emission factors, methane recovery etc. are European rather than national data. This should also be seen as a strength of the model: the GHG emissions have been estimated using a similar approach for all 28 countries which should make the estimations more suitable for comparisons.

In the previous working papers two sensitivity analyses were made, one using the OECD projections for economic development and another testing the importance of the methane recovery rates. As the latter turned out to have significant influence, this issue was decided to be investigated further.

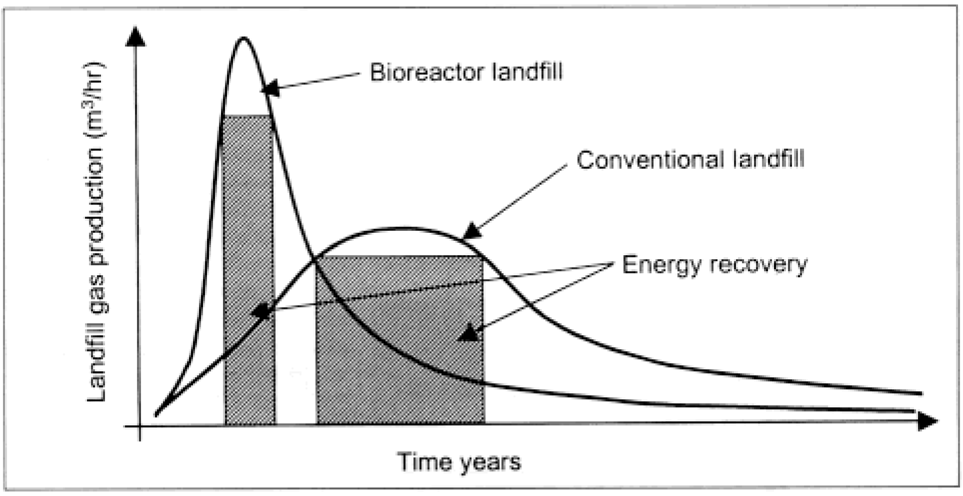
10.1. Methane modelling

Landfilling, and the associated methane emissions, is the largest direct contributor to global warming within the waste management system. Consequently, the choices that are made regarding methane recovery rates greatly affect the final results of the model. According to the sensitivity analysis performed earlier, the chosen modelling for methane recovery rates has major effects on the course and development of the net GHG emissions associated with the entire municipal waste management system.

The issue of methane recovery rates is one of the most complicated in the field of greenhouse gas accounting in the waste sector. The problem stems from the fact that the landfilling of waste at a given time produces landfill gases for a period of time that might extend for hundreds of years in the future. Therefore, no in-situ measurements can be taken in order to determine precisely the curve that depicts the methane emissions from a landfill. Those measurements can be made only as a large project spanning many years, rendering the effort extremely expensive. So far very few attempts have been made; those that have, have occurred mainly in the Netherlands (Oonk and Boom, 1995).

Another uncertainty that is directly related to the absence of in-situ measurements concerns the amount of methane or landfill gas emitted before and after the extraction period, namely the non-utilisation phases. From the moment that waste starts being landfilled in a newly constructed landfill until the time that the extraction system is installed, the emitted methane is not captured. Moreover, after a certain point in time, methane extraction is no longer economically feasible and many landfill owners cease to extract methane. A further quantity of methane occurs when the landfill closes. The relevant top layer is assumed to oxidise much of the methane into carbon dioxide but the exact ratio can usually only be estimated.

Figure 10.1 Landfill gas production according to landfill type.



Experts and scientists contacted in the course of this project maintain that the assumptions regarding all the non-utilisation phases include a great amount of uncertainty. The time intervals of these phases cannot be accurately defined neither can the methane emissions lifetime share that corresponds to each phase.

Moreover, this project considers a very large geographical region that includes many countries. The differences among landfills cannot be taken into account at such an aggregated level. Therefore, an “average” landfill is used to model the methane generation and extraction for each country.

10.2. Technological developments

The waste-oriented technologies have been booming, particularly in the EU, since the beginning of the 1990s. Lately, the need for improved efficiency and the goal of exploiting the maximum possible resources hidden in the waste have led to new emerging technologies such as pyrolysis, gasification and anaerobic digestion.

On the other hand existing well-established technologies are constantly being improved in order to compete better with the new options. More efficient equipment is being installed in landfills with the purpose of capturing more methane for energy recovery and containing the leachate. Incineration plants aim at increasing the conversion efficiency of energy by combining production of heat and electricity and utilising the excess steam for internal needs, etc.

The model presented in this paper includes only traditional treatment technologies, namely recycling/composting, landfilling and incineration. Moreover, these options remain the same for the entire projection period. Therefore, the quantities that undergo different treatment are accounted for as if they were treated via traditional means, which leads to false estimations of the results. The model, in order to take into account the different treatment possibilities, should incorporate modules for different technologies, especially anaerobic digestion which becomes more and more attractive.

The model also assumes that the technological efficiencies of the existing options remain constant throughout the investigated time period. Average European values are used that do not change over time. The reason for this assumption is that the uncertainty for future developments is quite high while the effect of these efficiencies on overall results is rather limited (see section below).

10.2.1. Incineration efficiency

The three main relevant technological efficiencies confronted within this model concern methane recovery and conversion efficiency in landfills, incineration efficiencies and the recycling substitution rate. The first is tackled in chapter 10.1. The recycling substitution rate is very difficult to investigate since it is strongly dependent on the input quality of waste, on which no information is available.

The GHG model assumes that all waste that received thermal treatment also produces recovered energy. There are still some plants operating for purely disposal purposes in the EU. However, according to recent work for the CEWEP, this assumption seems realistic (CEWEP, 2009). This work investigated incineration plants in EU-27 + Norway and Switzerland, responsible for treating around 72% of the total incinerated waste in this area for 2006. These plants presented an average efficiency value of 0.75 which is much higher than the limit for considering a plant as an R1 facility according to the revised Waste Framework Directive. Therefore, it is safe to claim that the modelled average incinerator, used for calculating GHG emissions, is rather representative for the European situation.

The model uses a 33% efficiency for converting the energy content of the municipal waste into electricity and 56% efficiency for the conversion into heat. In an attempt to understand how important the choice of these numbers is for the overall GHG emissions, a sensitivity analysis has been performed. A reduction of 10% is applied on the efficiencies and the total net GHG emissions should be compared. However, the aggregation of the emissions into net GHG emissions appears problematic for the sensitivity analysis when the values approximate zero (mathematic problem). Therefore, it would be more useful to observe the effect of the incineration efficiency on the avoided emissions only.

Table 10.1 compares the total avoided emissions of the baseline scenario with the emissions produced by a reduction in the incineration efficiency. The occurring difference is much smaller than the 10% induced change, it fluctuates around 2-3%. It also shows that when recycling was not preferred in the European MSW management systems (before 2000) the importance of incineration on the avoided emissions was higher. After 2000, when recycling slowly became dominant, the importance of incineration started to reduce.

Table 10.1 Dependence of avoided GHG emissions in the EU-27 + Norway and Switzerland on the incineration efficiency, according to the baseline scenario, in million tonnes CO_2-equivalents

	Baseline Scenario, avoided emissions (million tonnes CO_2-eq)	Baseline scenario, but with 10% reduction in incineration efficiency	Difference (%)
1990	-27.41	-26.54	-3.16%
1995	-37.54	-36.39	-3.08%
2000	-61.85	-60.44	-2.27%
2005	-85.62	-83.84	-2.07%
2010	-96.06	-94.17	-1.97%
2015	-113.17	-111.02	-1.90%
2020	-120.73	-118.47	-1.87%

As a result, the choice for the incineration conversion efficiencies is not very important for the overall results, compared to other parameters, such as the methane recovery rates.

10.3. Improvement options

10.3.1. Alternative energy mix

The future energy mix can be expected to change towards including more renewable and nuclear energy while the share of fossil fuels can be expected to decline. Thus, it would be interesting to analyse how a change in the energy scenario would affect the net GHG emissions as well as the relative effects of landfill, incineration and recycling. However, due to limited resources and uncertainty over future developments, this has not been modelled in this project, only a rough sensitivity analysis has been done for a scenario with a much lower carbon intensity of the energy mix in 2020 (section 7.1.3).

10.3.2. Policy effectiveness analyses

The model can be suitable for making policy effectiveness analyses of for example the Landfill Directive. By setting up different scenarios with changed values for landfill rates, waste composition etc. it would be possible to “measure” the effect of political initiatives.

10.4. Validation of the model

The model has already been validated in many respects, such as comparisons with alternative data sources. However, with the public launch of the results of the analysis in 2008, we have received many comments, questions and suggestions linked to the modelling of GHG emissions from municipal waste. Several other projects have been or are dealing with these issues as well, and the ETC/SCP could seek to improve the exchange of knowledge within these projects (e.g. Prognos et al, 2009). Firstly by carrying out a review of existing and ongoing studies launched within the last couple of years, and secondly to invite experts outside the ETC/SCP and the EEA for discussions on this specific issue.

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Annex I: Abbreviations and country codes

BMW	Biodegradable municipal waste
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CRF	Worksheet called Common Reporting Format for the UNFCCC
DOC	Degradable organic carbon
EU-15 + Norway and Switzerland	AT, BE, DE, DK, ES, FI, FR, GR, IE, IT, LU, NL, PT, SE, UK, CH, NO
FOD	First Order Decay
GHG	Greenhouse gas (e.g. carbon dioxide, methane)
GVA	Gross value added in the production sector
IPCC	Intergovernmental Panel on Climate Change
MCF	Methane correction factor
MSW	Municipal (solid) waste
MSWF	Fraction of municipal waste disposed to landfills
MSWT	Total municipal waste generated (million tonnes /year)
EU-12	BG, CZ, EE, HU, LT, LV, MT, PL, RO, SI, SK
N_2O	Nitrous oxide
NIR	National Inventory Reports for the UNFCCC
NMVOCs	Non-methane volatile organic compounds
OX	Oxidation factor
SWDS	Solid Waste Disposal Site
UNFCCC	United Nations Framework Convention on Climate Change
BS	Baseline Scenario
LD	Full compliance with the Landfill Directive scenario
LB	Total Landfill Ban scenario

	EU-15+ CH, NO		*EU-12*
AT	Austria	BG	Bulgaria
BE	Belgium	CY	Cyprus
DE	Germany	CZ	Czech Republic
DK	Denmark	EE	Estonia
GR	Greece	HU	Hungary
ES	Spain	LT	Lithuania
FI	Finland	LV	Latvia
FR	France	MT	Malta
IE	Ireland	PL	Poland
IT	Italy	RO	Romania
LU	Luxembourg	SI	Slovenia
NL	The Netherlands	SK	Slovakia
PT	Portugal		
SE	Sweden		
UK	United Kingdom		
NO	Norway		
CH	Switzerland		

Annex II: Assumptions for estimation of GHG emissions per country

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
Austria	Data on MSW composition, constant 1990-2002. Parameters for the model.	Landfilled waste shares 1995-2008: from Eurostat, not from the CRF.
Belgium	Not used, just generation data for cross checking in 1990-2003.	Model parameters from IPCC guideline. MSW composition and DOC (Degradable Organic Carbon) from IPCC guideline, (Western Europe).
Cyprus	No reporting to the UNFCCC has been made.	Data on generation of BMW in 1995: Eurostat
Czech Republic	Parameters: IPCC Guidelines Some of the values used for the parameters are quite different from the IPCC Guidelines, and can be discussed.	Estimated: ▪ Composition of MSW: from OECD, assumed constant composition. ▪ CH4 collection correction not needed because there is no information on industrial waste.
Denmark	All data available 1990-2005, including composition of non-MSW Assumption of constant waste composition of each fraction 1990-2005.	
Estonia	Total amounts of MSW 1993-2003. In Guideline 2006 (Estonian Env. Information Centre data): total amounts of industrial waste Some of the values used for the parameters are quite different from the guidelines, and can be discussed.	Estimated: ▪ Composition of MSW:1993-2003 assumed constant composition, taken from IPCC 2006 guideline 'Eastern Europe' (no info from OECD) ▪ 2) total gas recovery taken from NIR, assumed all coming from MSW
Finland	All data available 1990-2005, including composition of MSW and non-MSW. Assumption of constant waste composition of each fraction 1990-2005 based on 1990 composition.	Call with 'garden waste' substituted by 'other degradable waste', and a new half-life value of 13 years used, as indicated in the NIR 2005 FI. Values of industrial DOC in 1990-2003 from the NIR 2005 FI are used instead of an average DOC for industrial waste of 0.105 which would have been used instead and which underestimates emissions in 1990 and overestimates in 2003. NIR 2005 FI indicates a decrease in emissions of 30% from 1990 to 2003. That is only to be seen when the years before 1990 are included in the modelling.
France	Follows IPCC	
Germany	Parameters from the NIR and CRF. Methane recovery percentages extracted from CRF 2003 figure, after assumed constant, and linear increase in the period 1985-2003, following information in the NIR 2005 DE. The information on MCF in the NIR 2005 DE matches well with assumptions made.	Landfill share from Eurostat, composition from OECD.
Greece		Assumed dry temperate weather.

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
		Only the recovery percentages in the years 1999-2003 have been used for the projection of recovery in 2004-2020.
Hungary	Follows IPCC	
Ireland	Methane oxidisation is in CRF-file reported to be 1. This would imply that no methane emission takes place as everything is oxidised. This is not realistic. The value is set to 0.1.	Methane recovery trend has been estimated using available data. The results from the linear regression are used in the years where no information on methane recovery is available. (NB! no good correlation)
Italy	The time lag considered in the Italian CRF-file is 25 years. This value is rather unrealistic as the recommendation from IPCC is 0-6 months. A value of 6 moths is used.	Assumed dry temperate weather The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2030. Linear regression (based on the years 1992-2003)
Latvia		No information on delay time and oxidisation factor. These are set to 6 months and 0 respectively. No information on composition of MSW landfilled. The composition of landfilled MSW is assumed to equal the composition in Poland.
Lithuania		A very limited amount of data is available for Lithuania. Following assumptions have been made: ▪ Delay time: 6 months ▪ Oxidisation factor: 0 ▪ Fraction of methane in developed landfill gas: 0.5 Only unmanaged landfill sites are used at the moment. It is assumed to be 25% shallow and 75% deep No information on composition of MSW landfilled. The composition of landfilled MSW is assumed to equal the composition in Poland. There is no information on methane recovery. Assumed to be zero.
Luxembourg		A very limited amount of data is available for Luxembourg. The following assumptions have been made: ▪ Delay time: 6 months ▪ Oxidisation factor: 0 ▪ Fraction of methane in developed landfill gas: 0.5 There is no information on methane recovery. Assumed to be zero. Data on composition of MSW are from OECD statistics. No information on types of landfills used. It is assumed that at present and in future only managed landfills are used.
Malta		Malta has not reported to the IPCC. Thus, no

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
		data on parameters and landfills are available. Hence, several assumptions on key parameters have to be made: ▪ Delay time: 6 months ▪ Oxidisation factor: 0 ▪ Fraction of methane in developed landfill gas: 0.5 The present types of applied landfills are assumed to be unmanaged and consist of 50 % shallow and 50 % deep. It is assumed that no methane recovery is taking place. The composition of landfilled MSW is assumed to correspond to MSW landfilled in Italy. Assumed dry temperate weather.
Netherlands	Oxidation factor is set to 0.1. The Netherlands base calculations on a rather unrealistic value (0.58) which is not clearly documented (as required). Thus, the reported value is not used. The time lag considered is not specified. A time lag of 6 months is used. Landfilled MSW composition : the category ‘other’ is assumed to consist of 50% food waste 50% inert. The composition of Landfilled MSW is recalculated using the reported figures but excluding building waste and ashes as these are not included in MSW.	Assumed linear decrease in landfill share from 80% in 1989 to 29% in 1995. The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2030. Linear regression (based on the years 1990-2003)
Portugal	The oxidisation factor is by Portugal reported to be 0.0 or 0.1. It is chosen to use the default value (zero). The time lag considered in the Portuguese CRF-file is >=20 years. This value is rather unrealistic as the recommendation from IPCC is 0-6 months. A value of 6 months is used.	Assumed dry temperate weather. The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2030. Linear regression (based on the years 2000-2003).
Poland		No information on time lag available from Poland. 6 months is used. Information for recovery of methane is only given for one year (2003) where the recovery amounted to 6.9%. In order to estimate the level of recovery in future years an annual increase of 5 % is assumed.
Slovak Republic	The latest reported valued (2003) for the oxidisation factor is used: 0 A relatively low share of landfilled MSW in the mid-end 90s causes a conspicuous dive in the results graph	Landfilled MSW composition: the fraction ‘non specified’ is assumed to consist of 50% food waste, and 50% inert No information of managed vs. unmanaged disposal sites available. Data from Poland is used as a proxy

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
		No information on time lag available from Slovakia. 6 months is used. No information methane fraction in landfill gas available from Slovakia. A ratio of 0.5 is used. No SWDS are recovering methane.
Slovenia	Time lag is set to 6 months. NIRs from Slovenia indicate use of unrealistic time lags (23-39 years). The recommendation from IPCC is 0-6 months.	Fraction of methane in landfill gas is set to 0.47. According to the NIR the value varies slightly over time – this is not taken into account. Assumed dry temperate weather The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2020. Linear regression (based on the years 1996-2003)
Spain	Composition 1990-2003.	Assumed dry temperate weather. Landfill gas recovery: the figures in NIR are unrealistic. The figures used in the model are estimated from Willumsen (2003). These figures need to be refined in a later phase of the project.
Sweden	The composition of MSW landfilled is recalculated from CRF figures discarding the content of sludge. Furthermore, napkins are assumed to consist of 1/3 paper/cardboard, 1/3 textiles and 1/3 plastics	Linear regression on methane recovery trend (based on data from 1998-2003).
United Kingdom	The level of methane recovery reached in 2003 was 68 %. This is considered very high, and this value is kept in the prospective analysis.	Landfilled MSW composition: ‘miscellaneous’ is assumed to consist of 50% food waste, and 50% inert. Oxidation factor is set to 0.1. UK reports base calculations on a rather unrealistic value (0.9) which is not used

Annex III: Landfill and incineration rates according to the baseline scenario.

Table III.1 Municipal waste landfilled, 1995-2008

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Austria	43%	33%	32%	32%	32%	31%	30%	29%	28%	7%	6%	4%	3%	3%
Belgium	44%	39%	27%	23%	21%	16%	12%	11%	10%	8%	7%	5%	5%	5%
Bulgaria	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Czech Republic	100%	100%	100%	98%	95%	93%	91%	88%	86%	84%	83%	85%	84%	83%
Denmark	17%	13%	11%	11%	11%	10%	7%	6%	5%	5%	5%	5%	5%	4%
Estonia	99%	100%	100%	100%	100%	98%	94%	97%	84%	72%	73%	67%	64%	90%
Finland	65%	67%	63%	63%	58%	61%	61%	63%	60%	59%	59%	58%	53%	50%
France	45%	46%	46%	45%	44%	43%	41%	39%	38%	36%	34%	36%	36%	36%
Germany	46%	43%	39%	37%	30%	27%	27%	21%	19%	18%	9%	1%	1%	1%
Greece	94%	94%	91%	91%	91%	91%	91%	91%	92%	90%	88%	87%	77%	77%
Hungary	91%	91%	91%	91%	91%	91%	90%	91%	91%	90%	85%	82%	79%	74%
Ireland	92%	92%	91%	91%	90%	89%	87%	80%	73%	67%	66%	64%	63%	62%
Italy	90%	87%	83%	77%	73%	70%	63%	60%	54%	52%	49%	48%	46%	44%
Latvia	100%	100%	100%	100%	100%	100%	98%	98%	96%	93%	94%	95%	94%	93%
Lithuania	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	98%	97%	96%	96%
Luxembourg	31%	33%	29%	29%	26%	27%	26%	25%	24%	25%	26%	26%	25%	25%
Malta	76%	78%	81%	83%	86%	85%	85%	92%	89%	86%	85%	81%	93%	97%
Netherlands	30%	22%	13%	10%	8%	11%	9%	9%	3%	2%	2%	3%	3%	1%
Norway	73%	67%	62%	65%	55%	55%	26%	24%	21%	21%	20%	19%	19%	18%
Poland	98%	98%	97%	98%	98%	98%	96%	97%	97%	95%	92%	91%	90%	87%
Portugal	80%	79%	78%	77%	75%	69%	67%	71%	66%	67%	62%	64%	63%	65%
Romania	100%	100%	100%	100%	100%	100%	98%	98%	100%	99%	98%	99%	99%	99%
Slovakia	86%	86%	85%	85%	85%	84%	84%	84%	84%	83%	83%	83%	82%	83%
Slovenia	97%	95%	93%	90%	92%	94%	97%	87%	82%	63%	64%	69%	66%	66%
Spain	84%	82%	80%	78%	73%	68%	67%	61%	61%	58%	56%	60%	57%	57%
Sweden	35%	32%	32%	28%	25%	23%	23%	20%	14%	9%	5%	5%	4%	3%
Switzerland	13%	11%	11%	11%	10%	6%	6%	2%	1%	0%	0%	0%	0%	0%
United Kingdom	84%	86%	87%	84%	83%	82%	80%	78%	74%	69%	65%	60%	57%	55%
EU-27 + CH, NO	**68%**	**67%**	**64%**	**62%**	**59%**	**57%**	**55%**	**52%**	**49%**	**47%**	**43%**	**41%**	**40%**	**40%**

Table III.2 Municipal waste projected to be landfilled, 2009-2020

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%	2%	2%
Belgium	4%	4%	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%
Bulgaria	100%	96%	93%	89%	86%	82%	79%	75%	75%	75%	75%	75%
Czech Republic	80%	77%	75%	72%	70%	67%	65%	62%	61%	61%	60%	60%
Denmark	4%	4%	4%	4%	3%	3%	3%	3%	3%	3%	3%	3%
Estonia	80%	78%	76%	74%	71%	69%	67%	65%	65%	65%	65%	65%
Finland	45%	44%	43%	42%	40%	39%	38%	37%	37%	37%	37%	37%
France	33%	32%	31%	30%	30%	29%	28%	27%	27%	27%	27%	27%
Germany	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Greece	75%	73%	71%	69%	67%	65%	63%	61%	61%	61%	61%	61%
Hungary	71%	69%	67%	65%	63%	61%	59%	57%	57%	57%	57%	57%
Ireland	60%	58%	56%	54%	51%	49%	47%	45%	45%	45%	45%	45%
Italy	42%	40%	37%	35%	32%	30%	27%	25%	25%	25%	25%	25%
Latvia	90%	87%	84%	81%	79%	76%	73%	70%	70%	70%	70%	70%
Lithuania	95%	93%	91%	89%	86%	84%	82%	80%	80%	80%	80%	80%
Luxembourg	24%	23%	22%	21%	19%	18%	17%	16%	16%	16%	16%	16%
Malta	95%	91%	88%	84%	81%	77%	74%	70%	69%	68%	67%	66%

Netherlands	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Norway	15%	14%	14%	13%	12%	11%	11%	10%	10%	10%	10%	10%
Poland	84%	82%	80%	78%	76%	74%	72%	70%	69%	68%	67%	66%
Portugal	62%	60%	57%	55%	52%	50%	47%	45%	45%	45%	45%	45%
Romania	95%	91%	88%	84%	81%	77%	74%	70%	70%	70%	70%	70%
Slovakia	80%	77%	75%	72%	70%	67%	65%	62%	62%	62%	62%	62%
Slovenia	64%	63%	61%	60%	59%	58%	56%	55%	55%	55%	55%	55%
Spain	55%	53%	50%	48%	45%	43%	40%	38%	38%	38%	38%	38%
Sweden	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%	2%	2%
Switzerland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
United Kingdom	50%	48%	46%	44%	41%	39%	37%	35%	35%	35%	35%	35%
EU-27 + CH, NO	**38%**	**36%**	**35%**	**34%**	**32%**	**31%**	**29%**	**28%**	**28%**	**28%**	**28%**	**28%**

Source: The rates have been calculated: municipal waste landfilled as % of municipal waste generated, based on Structural Indicator data from Eurostat. For some countries national data or data reported to NIR have been used in selected years.

Table III.3 Municipal waste incinerated, 1995-2008

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Austria	11%	10%	10%	9%	9%	10%	10%	10%	11%	25%	26%	27%	29%	27%
Belgium	36%	35%	39%	36%	33%	34%	35%	35%	36%	35%	37%	36%	35%	36%
Bulgaria	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Czech Republic	0%	0%	0%	2%	4%	6%	8%	10%	13%	15%	15%	13%	13%	13%
Denmark	52%	50%	54%	53%	50%	53%	57%	56%	54%	55%	54%	53%	53%	54%
Estonia	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Finland	0%	0%	5%	6%	8%	10%	9%	9%	11%	12%	9%	9%	12%	17%
France	37%	35%	34%	33%	33%	33%	33%	34%	34%	35%	36%	33%	32%	32%
Germany	18%	20%	20%	21%	21%	22%	23%	22%	23%	25%	29%	34%	34%	35%
Greece	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hungary	7%	7%	7%	7%	7%	8%	8%	7%	6%	4%	7%	8%	9%	9%
Ireland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
Italy	5%	6%	7%	7%	7%	7%	8%	8%	9%	10%	11%	11%	11%	11%
Latvia	0%	0%	0%	0%	0%	0%	1%	2%	2%	2%	1%	1%	0%	0%
Lithuania	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	1%	0%	0%
Luxembourg	61%	61%	60%	57%	59%	55%	55%	54%	50%	51%	50%	50%	50%	50%
Malta	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Netherlands	27%	33%	40%	38%	40%	36%	38%	36%	39%	39%	39%	38%	38%	39%
Norway	13%	13%	13%	13%	15%	15%	30%	31%	33%	34%	35%	36%	37%	38%
Poland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Portugal	10%	11%	13%	14%	15%	19%	20%	20%	22%	22%	22%	20%	19%	19%
Romania	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Slovakia	10%	10%	10%	10%	11%	11%	11%	11%	11%	13%	12%	13%	11%	10%
Slovenia	0%	0%	0%	0%	0%	0%	0%	1%	1%	2%	0%	1%	0%	1%
Spain	7%	7%	9%	9%	8%	7%	7%	7%	7%	6%	8%	9%	9%	9%
Sweden	39%	38%	37%	38%	38%	39%	39%	40%	45%	46%	49%	46%	47%	49%
Switzerland	49%	47%	47%	46%	47%	49%	47%	52%	51%	51%	49%	50%	49%	50%
United Kingdom	9%	7%	6%	7%	7%	7%	7%	8%	8%	8%	8%	9%	9%	10%
EU-27 + CH, NO	15%	15%	16%	16%	16%	16%	17%	17%	18%	19%	20%	21%	20%	21%

Table III.4 Municipal waste projected to be incinerated, 2009-2020

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	28%	28%	29%	29%	29%	29%	30%	30%	30%	30%	30%	30%
Belgium	36%	36%	36%	36%	37%	37%	37%	37%	37%	37%	37%	37%
Bulgaria	0%	1%	1%	2%	3%	4%	4%	5%	5%	5%	5%	5%
Czech Republic	13%	13%	14%	14%	14%	14%	15%	15%	15%	15%	15%	15%
Denmark	54%	54%	54%	54%	55%	55%	55%	55%	55%	55%	55%	55%
Estonia	1%	2%	2%	3%	3%	4%	4%	5%	5%	5%	5%	5%

Finland	20%	21%	21%	22%	23%	24%	24%	25%	25%	25%	25%	25%
France	35%	35%	36%	36%	37%	37%	38%	38%	38%	38%	38%	38%
Germany	35%	36%	36%	37%	38%	39%	39%	40%	40%	40%	40%	40%
Greece	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hungary	10%	10%	11%	11%	11%	11%	12%	12%	12%	12%	12%	12%
Ireland	5%	6%	6%	7%	8%	9%	9%	10%	10%	10%	10%	10%
Italy	10%	10%	11%	11%	12%	12%	13%	13%	13%	13%	13%	13%
Latvia	1%	2%	2%	3%	3%	4%	4%	5%	5%	5%	5%	5%
Lithuania	1%	1%	2%	2%	3%	4%	4%	5%	5%	5%	5%	5%
Luxembourg	51%	51%	52%	52%	53%	53%	54%	54%	54%	54%	54%	54%
Malta	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Netherlands	40%	41%	41%	42%	43%	44%	44%	45%	45%	45%	45%	45%
Norway	40%	40%	41%	41%	41%	41%	42%	42%	42%	42%	42%	42%
Poland	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Portugal	20%	20%	21%	21%	21%	21%	22%	22%	22%	22%	22%	22%
Romania	0%	1%	1%	2%	3%	4%	4%	5%	5%	5%	5%	5%
Slovakia	11%	11%	11%	11%	12%	12%	12%	12%	12%	12%	12%	12%
Slovenia	0%	1%	1%	2%	3%	4%	4%	5%	5%	5%	5%	5%
Spain	10%	10%	10%	10%	11%	11%	11%	11%	11%	11%	11%	11%
Sweden	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Switzerland	50%	50%	51%	51%	51%	51%	52%	52%	52%	52%	52%	52%
United Kingdom	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
EU-27 + CH, NO	21%	22%	22%	22%	23%	23%	23%	23%	23%	23%	23%	23%

Source: The rates have been calculated: municipal waste incinerated as % of municipal waste generated, based on Structural Indicator data from Eurostat. For some countries national data or data reported to NIR have been used in selected years.

Annex IV: The projection model

The generation of waste relates to a number of economic activities, and different economic activities generate different streams and quantities of waste. Looking at past developments in such streams, economic activities and the size of population, the relations between amounts of waste, economic activities and population are analysed. If these relations have been proven in the past, and forecasts of economic activities and the population growth are available, the relations may be combined with the economic and population forecasts in order to generate projections/scenarios for the development in the amounts of waste.

Mathematically, the general equation tested on past observations is:

$$\log(w_i) = a_{0i} + a_{1i} \cdot (s_i \cdot \log(A1_i) + (1 - s_i) \cdot \log(A2_i)) + a_{2i} \cdot \log(pop) + a_{3i} \cdot T + d \cdot Dummy$$

Eq. (1)

where w_i is the amount of waste of waste stream *i*, $A1_i$ and $A2_i$ are two different economic activities, e.g., the private consumption of categories of goods or the production within various branches, pop is the size of the population and T is time. T is included in the equation to catch trend-wise changes in the amount of waste. Such trends may occur due to structural changes, i.e. changes in the relative size of waste generating activities, or changes in the waste collection systems, what is included in the individual waste streams and how much of the waste generated is collected. Past trends may be extended into projections. However, large historical trends are not likely to continue in the long run. If they are to continue, this requires some specific explanation. Therefore, the model includes a possibility to phase out the trend over a specified period. Finally, the equation includes a dummy-variable that is zero in some years and one in other years. Dummy-variables may be included to correct for data breaks or outlayers.

The parameters s_i, α_{0i}, α_{1i}, α_{2i} and α_{3i} are estimated on past observations. Interpreting parameters, s_i is the share of waste stream i linked to the economic activity $A1_i$, and $(1 - s_i)$ is the share linked to activity $A2_i$, i.e., s_i is a figure between 0 and 1. If it is known what share of the waste stream is related to activity $A1_i$, s_i may be restricted to this value. If time series for the share are available the two equations relating the waste streams to $A1_i$ and $A2_i$, respectively might be formulated. However, if the share is not known, but only that the waste stream is related to two activities, the aggregated data for the waste stream are used to estimate s_i. Restricting s_i to either 1 or 0 implies that the waste stream is only linked to one economic activity, and Eq. (1) reduces to Eq. (2). The parameter α_{1i} is the elasticity of waste stream *i* with respect to the activity level, i.e., if the activity level increases by 1%, the amount of waste increases by $\alpha_{1i}\%$.α_{2i} is the elasticity with respect to changes in the population and α_{3i} is a trend-wise annual change in the amount of waste.

$$\log(w_i) = a_{0i} + a_{1i} \cdot \log(A_i) + a_{2i} \cdot \log(pop) + a_{3i} \cdot T + d \cdot Dummy \qquad \text{Eq. (2)}$$

Equations (1) and (2) contain two sets of level variables $A1_i$, $A2_i$ and pop. Reasonable free estimations of parameters to both sets of variables are difficult to obtain and not easy to interpret. Therefore, in order to estimate Eq. (1) or Eq. (2), a number of parameter restrictions are imposed. However, the equation is formulated in the model as Eq. (1) and the parameter values (restricted or not) are specified in an input sheet.

Assuming that $a_{1i} = 1.0$, Eq. (2) reduces to:

$$\log\left({w_i}/{A_i} \right) = a_{0i} + a_{2i} \cdot \log(pop) + a_{3i} \cdot T + d \cdot Dummy \qquad \text{Eq. (3)}$$

i.e., the waste coefficient depends on the size of population and time.

Assuming $a_{2i} = 1.0$ Eq. (2) reduces to:

$$\log\left({w_i}/{pop} \right) = a_{0i} + a_{1i} \cdot \log(A_i) + a_{3i} \cdot T + d \cdot Dummy$$

i.e., the waste per inhabitant depends on the level of activity and time. This may be somewhat difficult to interpret. An easier equation to interpret is that the waste per inhabitant depends on the activity level per inhabitant and time. To obtain this formulation, the parameter restriction on Eq. (2) is $a_{2i} = 1.0 - a_{1i}$ and Eq. (2) reduces to:

$$\log\left({w_i}/{pop} \right) = a_{0i} + a_{1i} \cdot \log\left({A_i}/{pop} \right) + a_{3i} \cdot T + d \cdot Dummy \qquad \text{Eq. (4)}$$

Furthermore, imposing the restriction $a_{2i} = 0.0$ on Eq. (3), or $a_{1i} = 0.0$ on Eq. (4) and leaving out dummy-variables, the equations reduce to an annual change in the waste coefficient, or in the amount of waste per inhabitant:

$$\log\left({w_i}/{A_i} \right) = a_{0i} + a_{3i} \cdot T \qquad \text{or} \qquad \log\left({w_i}/{pop} \right) = a_{0i} + a_{3i} \cdot T \qquad \text{Eq. (5)}$$

Taking first differences in Eq. (5), it is seen that a_{3i} is the annual % change in the waste coefficient, or in the amount of waste per inhabitant:

$$\Delta \log\left({w_i}/{A_i} \right) \quad or \quad \Delta \log\left({w_i}/{pop} \right) = a_{3i}$$

i.e., if $a_{3i} = 0.02$, the waste coefficient, or amount of waste per inhabitant increases by 2% p.a.

Finally, if $a_{3i} = 0.0$ in Eq. (5), the equation reduces to assuming a constant waste coefficient, or amount of waste per inhabitant:

$$\log\left({w_i}/{A_i} \right) \quad or \quad \log\left({w_i}/{pop} \right) = a_{0i} \qquad \text{Eq. (6)}$$

If a_{0i} is estimated on past values, it represents the average waste coefficient or amount of waste per inhabitant. An alternative is to set a_{0i} equal to the value in the last observable year. This may be preferable if it is evaluated that the quality of waste data has improved over time, or that the most recent value best mirrors the future waste coefficient.

Testing the various specifications, Eq. 1 is, in general, estimated imposing the parameter restrictions given in Table IV.1. However, the inclusion of one or two activity variables is mainly decided from a priory consideration, i.e., for most of the waste streams, s_i is priory restricted to one or zero. Free estimation of s_i is tested only for waste streams linked both to private consumption categories and to the production within sectors. In the model (and in the following pages), the variable $A1_i$ is the private consumption, or some categories thereof, and $A2_i$ is the gross value added within some sectors. That is, if a waste stream is linked to private consumption, only, s_i is restricted to one and if a waste stream is linked to gross value added in some sectors, s_i is restricted to zero.

A general problem with modelling streams of waste is the limited number of historical observations. Given few historical observations, the number of parameters that may be freely estimated is also limited, and for a number of waste streams, this also limits the number of equations tested.

Table IV.1. Combinations of parameter restrictions in Eq. (1)

Equation \ parameter	s_i	a_0	a_1	a_2	a_3
eq. (1)	free	free	free	free	free
eq. (2)	1.0	free	free	free	free
eq. (3)	1.0	free	1.0	free	free
eq. (4)	1.0	free	free	1-a_1	free
eq. (4) alternative	1.0	free	free	1-a_1	0.0
eq. (5) activity	1.0	free	1.0	0.0	free
eq. (5) population	1.0	free	0.0	1.0	free
eq. (6) activity	1.0	free	1.0	0.0	0.0
eq. (6) population	1.0	free	0.0	1.0	0.0

In general, dummy variables are defined to be zero in projections, but may in the model be used for including exogenous evaluated changes in specific waste streams. If a dummy variable becomes one in the projection and the coefficient to this is 0.02, the waste stream increases by 2% in the year the dummy variable changes from zero to one.

Forecast methodology

In analyses of past developments, the economic activity variables are taken from Eurostat (http://epp.eurostat.ec.europa.eu) and in the forecasts, the two European Commission's baseline scenarios (see chapter 3) are used. However, the two sets of data have different classifications and base-years. The Eurostat data are in constant 1995-prices and the baseline scenarios are in constant 2000-prices. The activity data used are household consumption expenditure by category of goods.

Forecast of Household Consumption Expenditure

The baseline scenarios only forecast total private consumption expenditures. But in the development analyses of the amount of waste, for some waste streams, the amount is linked to the consumption of categories of goods, e.g., municipal waste is mainly linked to the consumption of food, beverage and clothing.

To forecast categories of private consumption, the share of the category in total private consumption is simply calculated and it is assumed that past trends in shares continue in the future, i.e.:

Share of category *f* at time *t*: $Sf_t = Cf_t / Ct_t$

Average change in share of *f* in the observation period $Apf = \sqrt[n]{Sf_t / Sf_{(t-n)}}$

Future share of *f*: $Sf_{t+1} = Sf_t \cdot Apf$

Future consumption of *f*: $Cf_{t+n} = Ct_{t+n} \cdot Sf_{t+n}$

where Cf_t is the consumption of category *f*, Ct_t is total private consumption and *Apf* is the average annual change in this past share.

This is a very simple way to generate forecasts of categories of private consumption, not taking into account differences in income and price elasticities of the different categories of private consumption. However, with only forecasts of total private consumption, and lack of a demand system, simple alternatives are difficult to find.

The problem of different price base-years in the historical data and the Baseline scenario is solved by transforming the Baseline scenario into 1995-prices using the 1995-values in the two base-year calculations, i.e., the ratio:

$$Ct_{1995(Eurostat)} \Big/ Ct_{1995(DG-TREN-baseline)}$$

Using this for the calculation of consumption by categories of goods, it is implicitly assumed that the development in prices for each category of goods is equal to the price development for the total private consumption.

The categories of final consumption expenditure of households by consumption purpose (COICOP 2-digit) used for the projection of municipal waste are:

fcps	Total final consumption expenditure
fcp01	Food and non-alcoholic beverages
fcp02	Alcoholic beverages, tobacco and narcotics
fcp03	Clothing and footwear